SILVA LUSITANA

08

Forest, Agriculture, Climate change and Food Security Challenges in the Mediterranean basin and Portugal: An Assessment

CADERNO TÉCNICO

Instituto Nacional de Investigação Agrária e Veterinária, I.P.

Ficha Técnica:

Título/Title: FOREST, AGRICULTURE, CLIMATE CHANGE AND FOOD SECURITY CHALLENGES IN THE MEDITERRANEAN BASIN AND PORTUGAL: AN ASSESSMENT

Edição/Edition: Instituto Nacional de Investigação Agrária e Veterinária

Editor Responsável: Miguel Pestana (INIAV)

Autores/Authors:

Raul Albuquerque Sardinha[1]
Miguel Nugent Pestana da Silva[**]
Abel Rodrigues[***]

Capa e **Composição**: Paulo Jesus Carvalho

Impressão: Europress - Indústria Gráfica

Tiragem: 500 exemplares

Nº Depósito Legal: 539920/24

ISBN: 978-972-579-081-6

Data: 2023

Morada/Address: INIAV: Av. da República, Quinta do Marquês, 2780-157 Oeiras, Portugal

☏ (351) 21 4403500

E-mail: silva.lusitana@iniav.pt

Patrocínio/Sponsor

[1] Forest Eng. (ISA, UTL); D.Ph. (Un. Oxford); FIWSc; Full Prof. (UTL), retired.

[**] Chemical Eng., MSc. (UNL); Ph.D. (UTAD); Senior Researcher (INIAV)

[***] Forest Eng. (ISA,UTL); MSc (IST, UTL); Ph.D (IST, UTL); Full Researcher (INIAV), Research Center affiliated: IDMEC (IST) and GeoBioTec (FCT, UNL)

FOREST, AGRICULTURE, CLIMATE CHANGE AND FOOD SECURITY CHALLENGES IN THE MEDITERRANEAN BASIN AND PORTUGAL: AN ASSESSMENT

Content Pag.

List of Tables Pag.

List of Figures Pag.

Acronymous

AFOLU	Agriculture, Forestry and Other Land Use
AGIF	Agência para a Gestão Integrada de Fogos Rurais [Agency for Integrated Rural Fire Management]
AGPDR	Autoridade de Gestão do PDR [PDR Management Authority]
AGPO SEUR	Autoridade de Gestão dos Programas Operacionais Temáticos [Management Authority for Thematic Operational Programs].
AI	Aridity Index
AIMMP	[Association of Wood and Furniture Industries of Portugal]
AKST	Agriculture Knowledge Sciences and Technology
AMOC	Atlantic Meridional Overturning Circulation
ANEPC	Autoridade Nacional de Emergência e Proteção Civil [National Emergency and Civil Protection Authority]
ANGEP	Agência Nacional para a Qualificação e o Ensino Profissional [National Agency for Qualification and Professional Education]
AR	Assessment Report (IPCC)
APA	Agência Portuguesa do Ambiente [Portuguese Environment Agency]
CAP	Common Agricultural Policy
CCDR	Comissão de Coordenação e Desenvolvimento Regional [Regional Coordination and Development Commission]
BAU	Business-as-usual
BVOCs	Biogenic Volatile Organic Compounds
CES	Forest Economic Accounts
CMAP	Centre Merged Analysis Prediction
CMIP5	Coupled Model Intercomparison Project - Phase 5
COP	Conference of Parties
CRU	Climate Research Unit (From East Anglia University, UK)
CNROA	Centro Nacional de Reconhecimento e Ordenamento Agrário [National Centre for Agrarian Recognition and Planning]
DQA	Diretiva Quadro da Água [Water Framework Directive]
DGADR	Direção-Geral de Agricultura e Desenvolvimento Rural [General Directorate of Agriculture and Rural Development]
DGAE	Direção Geral da Administração Escolar [General Directorate of School Administration]
DGAV	Direção Geral da Alimentação e Veterinária [General Directorate of Food and Veterinary]
DGE	Direção Geral de Educação [General Directorate of Education]
DGEG	Direção Geral de Energia e Geologia [General Directorate of Energy and Geology]
DGT	Direção Geral do Território [General Directorate of the Territory]

DRAP	Direção Regional de Agricultura e Pescas [Regional Directorate of Agriculture and Fisheries]
ECMRWF	European Centre for Median Range Weather Forecast
EGZIP	Entidade Gestora de Zona de Intervenção Florestal [Forest Intervention Zone Management Entity]
EIT	European Institute of Innovation & Technology
ENSO	El Niño/Southern Oscillation
Era-Net	European Research Area Networks
ERF	Effective Radiative Forcing
ETP	Exchange-Traded Product (financial instruments)
FDF	Forest Development Fund
FEA	Forest Economic Account
FEDER	Fundo Europeu para o Desenvolvimento Regional [European Fund for the Regional Development]
FEOGA	Fundo Social Europeu e Fundo Europeu de Orientação e Garantia para a Agricultura [European Social Fund and the European Orientation and Guarantee Fund for Agriculture]
FES	Forest Environmental Services
FLR	Forest and Landscape Restoration
FDF	Fundo de Fomento Florestal [Forest Development Fund]
FP7	Seventh framework programme of the European Community for research and technological development including demonstration activities.
GCM	Global Circulation Models
GHG	Greenhouse Gases
GNR	Guarda Nacional Republicana [Republican National Guard]
GPFLR	Global Partnership on Forest and Landscape Restoration
GPP	Gross Primary Production
GAPP	Gabinete de Planeamento, Políticas e Administração Geral [Office of Planning, Policies and General Administration]
GSL	Growing Season Length
GVA	Gross Value Added
GWP	Global Warming Potential
HGWPG	High Global Warming Potential Gases
HIC	Higher Income Countries
ICNF	Instituto da Conservação da Natureza e Florestas [Institute for the Conservation of Nature and Forests]
IEP	It is a training entity recognized by the National Emergency and Civil Protection Authority within the scope of Fire Safety in Buildings training.
IFAP	Instituto de Financiamento da Agricultura e Pescas [Institute of Agriculture and Fisheries Financing]
INIAV	Instituto Nacional de Investigação Agrária e Veterinária [National Institute of Agrarian and Veterinary Research]

IPCC	Intergovernmental Panel on Climate Change
JPIs	Joint Programming Initiatives
LIC	Lower Income Countries
LULUCF	Land Use, Land Use Change and Forestry
LUC	Land Use Change
MB	Mediterranean Basin
MDG	Millennium Development Goals
MENA	Middle East and North Africa
NAO	North Atlantic Oscillation
NCEP	National Centre for Environmental Prediction
NMCs	North Mediterranean Countries
NUT II	Nomenclature of Territorial units for Statistical purposes (NUTS II = Administrative regions)
NTFP	Non-Timber Forest Products
ONGA	Organizações não Governamentais do Ambiente [Environmental Non-Governmental Organizations]
OPF	Organização de Produtores Florestais [Forest Producers Organization]
OSCE	Organization for Security and Co-operation in Europe
OWDA	Old-World Drought Atlas
PDSI	Palmer Drought Severity Index
PEDAP	Programa Específico de Desenvolvimento da Agricultura Portuguesa [Specific Programme for the Development of Portuguese Agriculture], Reg. CEE 3828/85
PES	Payments for Environmental Services
PET	Potential Evapotranspiration
PID	Periods of Intense Drought
PJ	Polícia Judiciária [Judiciary Police]
PoU	Prevalence of Undernourishment
PSP	Polícia de Segurança Pública [Public Security Police]
PUB	Plans for the Use of Baldios Resources
RCM	Regional Circulation Models
RCP	Representative Concentration Pathway
RF	Radiative Forcing
SDG	Sustainable Development Goals
SEMCs	Southern and Eastern Mediterranean Countries
SIAM	Project "Climate Change in Portugal. Scenarios, Impacts and Adaptation Measures" (SIAM). SIAM I (1999-2002); SIAM II (2002-2006)
SOC	Soil Organic Carbon
SRES	Special Report Emissions Scenario
SROA	Serviço de Reconhecimento e ordenamento Agrário [Agrarian Recognition and Planning Service]

SSI	Soil Moisture Deficits Relative to the Climatology
SSPs	Shared Socioeconomic Pathways
SSS	Sea Surface Salinity
SST	Sea Surface Temperature
TAR	Third Assessment Report
TEV	Total Economic Value
TU	Total Use
TX90p index	Percentage of Days with Maximum Daily Temperature above 90^{th} percentile
UAA	Utilized Agricultural Area
UNFCCC	United Nations Framework Convention on Climate Change
TSPV	Total Standard Production Value
WEF	World Economic Forum
YWU	Year Work Unit

Acknowledgements:

We would like to record our thanks to Eng. Agrónomo Vitor Serrano for revising our work and making helpful comments and suggestions.

An Assessment of Climate Change and Food Security Challenges in the Mediterranean Basin and Portugal

Environnement : première richesse de l'homme depuis toujours.
Depuis toujours son pire ennemi et sa victime
Jacques Attali[2]

Abstract**:** This work aimed to summarize the current climate change situation in the Mediterranean basin, its influence on predictable meteorological and climate changes for Portugal, and the pending threats to Portuguese agriculture and forestry. The approach developed was interdisciplinary, involving fundamental concepts of climate analysis and soil erosion in the Mediterranean region and Portugal, as well as their respective impacts on forestry, agriculture, and animal production development.

Knowing that GHGs are the most significant factor in climate change, a brief analysis of current and predicted atmospheric concentrations is made. Projections show that in 2018, greenhouse gas concentrations reached new peaks, with global average mole fractions of carbon dioxide (CO_2) of 407.8 ± 0.1 parts per million (ppm), methane (CH_4) at 1869 ± 2 parts per billion (ppb) and nitrous oxide (N_2O) of 331.1 ± 0.1 ppb. These values represent 147%, 259% and 123% increases concerning pre-industrial levels (1750). Projections of global carbon concentrations until 2100 using 'CMIP5 Earth System Models' (Le Quéré[3] et al., 2013) that represent a broader range of complex interactions between the carbon cycle and the physical climate system consistently estimate positive feedback between climate and the carbon cycle, i.e. reduced natural sinks or increased natural sources of CO_2 in response to future climate change. In this context, the implications of climate change on terrestrial carbon reservoir biomes are mentioned. Evidence from observations of the climate system shows an increasing trend in surface temperature of about 0.03±0.01°C/year, which is 0.01°C higher than the current global trend. This trend implies that when the world exceeds the 1.5 ºC level identified in the Paris Agreement, the Mediterranean region will have already warmed by +2.2 ºC.

Regarding precipitation simulations, the trends that show that precipitation and relative humidity during the second half of the 20th century decreased in the Iberian Peninsula and Greece stand out, with the predominant trend for the 21st century pointing to a decrease between 1.5 and 7.3% for the entire Mediterranean basin, with maximum magnitude for the hot season (April to September). Future climate projections indicate a predominant shift towards a

---

[2] Attali, Jacques (1998.) – Dictionnaire du XXIe siècle. Paris, Fayard, 349 pp

[3] Le Quéré, C., Andres, R.J., Boden, T., Conway, T., Houghton, R.A., House, J.I., Marland, G., Peters, G.P., van der Werf, G.R., Ahlström,A., Andrew, R.M., Bopp, L., Canadell, J.G.,, Ciais, P., Doney, S.C. et al. (2013) - The global carbon budget 1959–2011. Earth Syst. Sci. Data, 5, 165–185, [www.earth-syst-sci-data.net/5/165/2013/]

precipitation regime with more significant interannual variability, greater intensity and greater extremes, lower frequency of rainy days and longer dry periods. The impacts of rising temperatures and negative trends in annual precipitation totals in most Mediterranean regions, as well as the increase in the number and intensity of extreme events and the limited availability of water for irrigated crops, are analysed, highlighting the substantial challenges posed to agriculture in this region and the particular vulnerability of food systems.

At a global level, the search for food security is the common thread that unites the different challenges to building a sustainable future. For Portugal, the high dependence of agriculture on the climate in conditions of decreasing water availability and a food system highly dependent on external markets justify an attempt to address the effects of climate change on agricultural activities, vulnerabilities, and possible necessary measures. The authors emphasize that the available studies are still limited to certain areas, and almost all aim to answer the questions about crop productivity. These considerations were complemented by an economic analysis that quantifies the forestry, agricultural and animal sectors.

To respond to future projections of Portuguese climate change and food security vulnerability, it is urgent to carry out more integrated studies that cover not only aspects of variations in crop yields but certainly include those that address available water resources and projected water needs without forgetting the policies that mitigate current vulnerabilities. The need to improve public and private capacities to implement mitigation and adaptation measures where forests play a prominent role was also mentioned. The needs for management policies that consider changes in land use and respective coverage were also mentioned, reinforced by efficient, innovative and coordinated research to provide resilience to climate change and contribute to food and nutritional security in Portugal.

Sumário: Este trabalho pretendeu sintetizar o quadro atual das alterações climáticas na bacia Mediterrânica e a sua influência nas alterações meteorológicas e climáticas previsíveis para Portugal bem como as ameaças pendentes na agricultura e silvicultura portuguesas. A abordagem desenvolvida foi de natureza interdisciplinar envolvendo conceitos fundamentais de análise climática, de erosão do solo na região Mediterrânica e em Portugal, assim como dos respetivos impactos no desenvolvimento da produção florestal, agrícola e animal.

Sabendo-se que os GEE são o fator mais significativo das mudanças climáticas, é feita uma breve análise sobre as concentrações atmosféricas atuais e previsíveis. As projeções mostram que em 2018, a concentração de gases de efeito estufa atingiram novos picos, com frações molares médias globais de dióxido de carbono (CO_2) de 407,8 ± 0,1 partes por milhão (ppm), metano (CH_4) em 1869 ± 2 partes por bilhão (ppb) e óxido nitroso (N_2O) de 331,1 ± 0,1 ppb. Esses valores representam respetivamente acréscimos de 147%, 259% e 123% dos níveis pré-industriais (1750). Projeções das concentrações globais de carbono até 2100 usando 'Modelos do Sistema Terrestre CMIP5' (Le Quéré et al., 2013) que representam uma gama mais ampla de interações complexas entre o ciclo do carbono e o sistema climático físico, estimam consistentemente o feedback positivo entre o clima e o ciclo do carbono, ou seja, sumidouros naturais reduzidos ou fontes naturais de CO_2 aumentadas em resposta a mudanças climáticas futuras. Neste contexto, são mencionadas as implicações das mudanças climáticas nos biomas de reservatórios de carbono terrestre. Evidências de observações do sistema climático mostram uma tendência crescente na temperatura da superfície de cerca de 0,03±0,01 ºC/ano, que é 0,01 ºC superior à atual tendência global. Esta tendência implica que quando o mundo ultrapassar o nível de 1,5 ºC identificado no Acordo de Paris, a região mediterrânica já terá aquecido +2,2 ºC.

Relativamente às simulações de precipitação, destacam-se as tendências que mostram que a precipitação e a humidade relativa durante a segunda metade do século XX diminuíram na Península Ibérica e na Grécia, sendo que a tendência predominante para o século XXI aponta para uma diminuição entre 1,5 e 7,3% para toda a bacia Mediterrânica, com magnitude máxima para a estação quente (abril a setembro). As projeções climáticas futuras indicam uma mudança predominante para um regime de precipitação com variabilidade interanual mais significativa, maior intensidade e maiores extremos, menor frequência de precipitação e períodos de seca mais longos. Os impactos do aumento das temperaturas, e as tendências negativas nos totais anuais de precipitação na maioria das regiões mediterrânicas, assim como o aumento no número e intensidade de eventos extremos, e a disponibilidade limitada de água para culturas irrigadas são analisadas, destacando-se os desafios substanciais colocados à agricultura nesta região e a particular vulnerabilidade dos sistemas alimentares.

A nível mundial, a busca pela segurança alimentar é o fio condutor que une os diferentes desafios à construção de um futuro sustentável. Para Portugal, a elevada dependência da agricultura do clima sob condições disponibilidade hídrica decrescente e um sistema alimentar altamente dependente dos mercados externos, justificam uma tentativa de abordagem aos efeitos das alterações climáticas nas atividades agrárias, vulnerabilidades e eventuais medidas necessárias. Os autores ressaltam que os estudos disponíveis ainda são limitados a determinadas áreas e são quase todos direcionados para responder a questões sobre a produtividade das culturas. Esta considerações foram complementadas por uma análise económica quantificadora das fileiras florestais, agrícolas e animais.

Para responder às projeções futuras das alterações climáticas portuguesas e da vulnerabilidade da segurança alimentar, é urgente a realização de estudos mais integrados que abranjam não só aspetos das variações nos rendimentos das culturas, incluindo certamente aqueles que abordam os recursos hídricos disponíveis e as necessidades hídricas projetadas, sem esquecer as políticas visando mitigar as vulnerabilidades atuais. Foi também mencionada a necessidade de melhoria das capacidades públicas e privadas para a implementação de medidas de mitigação e adaptação onde as florestas têm um papel de destaque. Foram igualmente mencionadas as necessidades de políticas de gestão que considerem as alterações no uso do solo e respetiva cobertura, reforçadas por investigação eficiente, inovadora e coordenada para proporcionar resiliência às alterações climáticas e contribuir para a segurança alimentar e nutricional em Portugal.

Résumé: Ce travail vise à synthétiser la situation actuelle du changement climatique dans le bassin méditerranéen et son influence sur les changements météorologiques et climatiques prévisibles pour le Portugal ainsi que les menaces imminentes pour l'agriculture et la foresterie portugaises. L'approche développée était de nature interdisciplinaire, impliquant les concepts fondamentaux de l'analyse du climat, de l'érosion des sols dans la région méditerranéenne et au Portugal, ainsi que leurs impacts respectifs sur le développement de la production forestière, agricole et animale.

Sachant que les GES constituent le facteur le plus important du changement climatique, une brève analyse des concentrations atmosphériques actuelles et prévues est réalisée. Les projections montrent qu'en 2018, les concentrations de gaz à effet de serre ont atteint de nouveaux sommets, avec des fractions molaires moyennes mondiales de dioxyde de carbone (CO_2) de 407,8 ± 0,1 parties par million (ppm), de méthane (CH_4) à 1 869 ± 2 parties par milliard (ppb) et oxyde nitreux (N_2O) de 331,1 ± 0,1 ppb. Ces valeurs représentent respectivement des augmentations de 147%,

259% et 123% des niveaux préindustriels (1750). Les projections des concentrations mondiales de carbone jusqu'en 2100 à l'aide des « modèles du système terrestre CMIP5 » (Le Quéré et al., 2013) qui représentent un éventail plus large d'interactions complexes entre le cycle du carbone et le système climatique physique, estiment systématiquement une rétroaction positive entre le climat et le cycle de le carbone, c'est-à-dire une réduction des puits naturels ou une augmentation des sources naturelles de CO_2 en réponse au changement climatique futur. Dans ce contexte, les implications du changement climatique sur les biomes réservoirs terrestres de carbone sont évoquées. Les observations du système climatique montrent une tendance à la hausse de la température de surface d'environ 0,03 ± 0,01°C/an, soit 0,01°C de plus que la tendance mondiale actuelle. Cette tendance implique que lorsque le monde dépassera le niveau de 1,5 ºC identifié dans l'Accord de Paris, la région méditerranéenne se sera déjà réchauffée de +2,2 ºC.

En ce qui concerne les simulations de précipitations, les tendances montrent que les précipitations et l'humidité relative ont diminué au cours de la seconde moitié du XXe siècle dans la péninsule ibérique et en Grèce. La tendance prédominante pour le XXIe siècle indiquant une diminution comprise entre 1,5 et 7,3% pour l'ensemble du bassin méditerranéen, avec une ampleur maximale pour la saison chaude (avril à septembre). Les projections climatiques futures indiquent une évolution prédominante vers un régime de précipitations caractérisé par une variabilité interannuelle plus importante, une plus grande intensité et des extrêmes plus importants, une fréquence de précipitations plus faible et des périodes sèches plus longues. Les impacts de la hausse des températures et des tendances négatives des précipitations annuelles totales dans la plupart des régions méditerranéennes, ainsi que l'augmentation du nombre et de l'intensité des événements extrêmes et la disponibilité limitée de l'eau pour les cultures irriguées, sont analysés, mettant en évidence les défis importants posés à l'agriculture dans cette région et la vulnérabilité particulière des systèmes alimentaires.

Au niveau mondial, la quête pour la sécurité alimentaire est le fil conducteur qui unit les différents défis pour construire un avenir durable. Pour le Portugal, la forte dépendance de l'agriculture au climat dans des conditions de diminution de la disponibilité en eau et un système alimentaire fortement dépendant des marchés extérieurs justifient une tentative de remédier aux effets du changement climatique sur les activités agricoles, les vulnérabilités et les éventuelles mesures nécessaires. Les auteurs soulignent que les études disponibles sont encore limitées à certains domaines et visent presque toutes à répondre aux questions sur la productivité des cultures. Ces considérations ont été complétées par une analyse économique quantifiant les secteurs forestier, agricole et animal.

Pour répondre aux projections futures du changement climatique et de la vulnérabilité de la sécurité alimentaire au Portugal, il est urgent de mener des études plus intégrées qui couvrent non seulement les aspects des variations des rendements des cultures, mais incluent certainement celles qui traitent des ressources en eau disponibles et des besoins en eau projetés, sans oublier les politiques visant à atténuer les vulnérabilités actuelles. La nécessité d'améliorer les capacités publiques et privées pour mettre en œuvre des mesures d'atténuation et d'adaptation là où les forêts jouent un rôle de premier plan a également été mentionnée. La nécessité de politiques de gestion prenant en compte les changements dans l'utilisation des terres et la couverture respective a également été mentionnée, renforcée par une recherche efficace, innovante et coordonnée pour assurer la résilience au changement climatique et contribuer à la sécurité alimentaire et nutritionnelle au Portugal.

Part I – The Mediterranean climate trends and context

1 - Global context

Agriculture is one of the most climate-dependent human activities, particularly in those regions prone to weather variability, adding constraints to those countries where large numbers of the population depend on small-scale agriculture. The Intergovernmental Panel on Climate Change (IPCC), 2007 states that by 2050, crop yield losses could reach up to 50% in some countries. Globally, crop yield losses will severely compromise food security, mostly in countries compounded by increased population and low adaptive capacity. In a review study of projected climate change effects in the 21st century, Zinyengere[4] et al. (2013) show that while there is significant uncertainty about the consequences of climate change in the late 20th century, projected changes further into the 21st century are robust, showing that climate change will negatively impact crops in many areas in the globe, including the Mediterranean.

Climate change and variations in population, dietary preferences, and technological innovation will be the major drivers of variations in agriculture and forestry activity in the coming decades. Among other economic sectors, agriculture is unique in its dependence on precipitation, temperature, and other climate variables and, thus, unique in its sensitivity to changes in those climate variables. While it is true that farmers around the world are used to dealing with the vagaries of climate, the fact is that changes are now taking place on a larger scale, bringing accrued challenges to farmers' multidimensional adaptation needed, mostly on what they can produce and eat, how to cultivate, where, when, and survive in the field.

Agricultural development and food security constitute today, as yesterday, a major strategic issue for the planet. The 2008 food crisis revealed the centrality of agricultural and food issues in strategic global affairs and climate change mitigation policies. Although the economic situation sometimes increases the level of political and media vigilance towards them, it is essential to remember that the food imperative has always been imposed in all places: it is a story as old as the world that it is not about to stop as we are now witnessing, due to unexpected market disruption of cereals from Ukraine and Russia. Undoubtedly, due to the reinforcement of demographic, food and climatic constraints, today's problems take on a more structural dimension. Although the world has made significant progress over the last 30 years in the fight against poverty, there are yet more than 800 million people going to bed hungry every day, and one in every ten people in the world is undernourished (FAO/IFAD/UNICEF and WHO[5], 2019). If action to address climate change does not hasten by accelerating innovation, reforming policies, resetting market incentives, and increasing financing, climate change dynamics is expected to

[4] Zinyengere, N., Crespo, O., Hachigonta, Sepo (2013) - Crop response to climate change in southern Africa: A comprehensive review. *Global and Planetary Change* 111:118–126

[5] FAO/IFAD/UNICEF/WFP/WHO (2019) – The State of Food Security and Nutrition in the World. Safeguarding against slowdown and downturns. Rome 215 pg.

add 2050 millions of people at risk of hunger, malnutrition, and poverty (Climate Change & Food Systems[6] (2022).

Achieving sustainable agricultural development without sacrificing the environment is a relevant challenge the world will need to meet, especially if we are to achieve poverty reduction, food security, and better nutrition and health, as world nations agreed under the adoption of the UN 2030 Agenda (Sustainable Development Goals). The importance of this objective derives from the fact that modern agriculture has altered the face of the planet more than any other human activity – from the production of food, animal feed, and other commodities to the markets and supply chains that connect producers to consumers. Globally, food systems are responsible for 80% of deforestation, 70% of freshwater use, and are the single greatest cause of terrestrial biodiversity loss (Elias[7] and Meinzen-Dick, 2021). Intensive monocultures and the destruction of forests and other ecosystems to enlarge the agriculture boundary for food and commodity production generate the bulk of carbon emissions associated with land use change (UNCCD[8], 2018.). Also increase of emissions of nitrous oxides from fertilizer use and methane emitted by ruminant livestock, as mentioned by Lynch[9] et al. (2021) comprises the largest and most potent share of agricultural green gas emissions.

In this sense, the indispensability of an integrated approach stems from the fact that historical and current patterns of use of natural resources result in increasingly negative impacts on the environment and human health. Because of the strong interrelationships between agriculture and the environment, a sensible approach for managing the vulnerability of food systems must integrate the economic, social, and environmental dimensions of development.

Population growth can affect the environment through higher consumption and increased use of natural resources. The additional release of CO_2 in the environment is a source of additional potential negative impacts on other factors. This includes the pressure it can create on resource governance, its effects on the likelihood of conflict over limited resources, and its consequences on rapid and unplanned urbanization. (OECD[10], 2016).

Resource extraction and processing of materials, fuels, and food make up about half of the total global greenhouse gas emissions (disregarding climate bearings related to land use) and more than 90 per cent of biodiversity loss and water stress. Moreover, natural resources and the related benefits, and environmental impacts, are unevenly distributed across countries and regions. These results illustrate that resources must be put at the centre of climate and biodiversity policies, to stay within a safe operating space and achieve common international targets.

Throughout the past 10,000 years of agriculture history, including the period of rapid growth and intensification during the Green Revolution, global mean temperatures have remained

---

[6] Climate Change & Food Systems (2022) – Global Food Policy Report. IFPRI. 189 pp.

[7] Elias, M., Joshi, D. and Meinzen-Dick, R. (2021) - Restoration for Whom, by Whom? A Feminist Political Ecology of Restoration. *Ecological Restoration*, 39 (1-2): 3-15.

[8] UNCCD (2018) - Committee for the Review of the Implementation of the Convention: Preliminary analysis – strategic objective 1: To improve the condition of affected ecosystems, combat desertification/land degradation, promote sustainable land management and contribute to land degradation neutrality, ICCD/CRIC (17)/2. [https://www.unccd.int/official-documentscric-17-georgetown-guyana-2019/iccdcric172].

[9] Lynch, J., Cain, M., Frame, D. and Pierrehumbert, R. (2021) - Agriculture's contribution to climate change and role in mitigation is distinct from predominantly fossil CO_2-emitting sectors. *Frontiers in sustainable food systems*, 4, 300 pp.

[10] OECD (2016) - International Migration Outlook, Paris. [http://dx.doi.org/10.1787/migr_outlook-2016-en]

within the range of about 1 °C from the current levels (Schellnhuber[11], Rahmstorf, and Winkelmann, 2016). The projected increase in temperature is significantly due to increases in GHG emissions, where CO_2 has an enormous contribution. Although vegetation has a significant role in CO_2 sinking, it is essential not to forget that globally, agriculture, forestry, and other land uses account for 24% of greenhouse emissions (Fig. 1), including direct emissions and those resulting from land-use changes and forestry, accounting to about 6.8 $GtCO_2$ $year^{-1}$.

Despite its long history, it was mainly in the last century that the agriculture sector has been profoundly altered by both natural and anthropogenic factors, including climate change, in the world economy, and in agricultural policies where we may mention, in the case of EU, the effects due to the Common Agricultural Policies. All these factors together including widespread poverty, inequality and marginalization, several powerful global drivers are compounding the nutrition crisis in developing countries, such as urbanization, the nutrition transition, environmental degradation, and climate change that are profoundly impacting the conditions in which agriculture activities are conducted, most directly through the changes in temperatures and precipitation patterns that affect crop productivity and agricultural land use patterns.

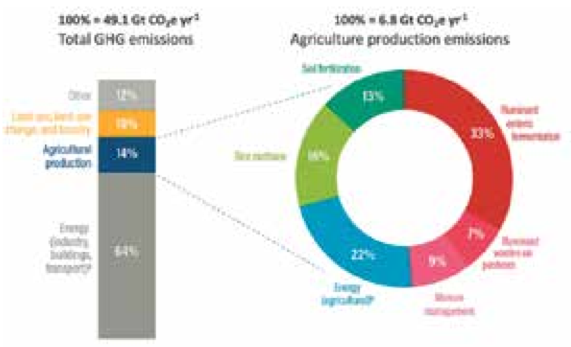


Fig. 1 - Global greenhouse gas emissions by agriculture production accounts for about one-quarter of total global emissions (values of 2012)
Data Excludes emissions from agricultural energy sources and the transport of food but Includes emissions from on-farm energy consumption and manufacturing of farm tractors, irrigation pumps and other machinery, as well as key inputs such as fertilizers.
Source: Creating a Sustainable Food Future. Final Report, July 2019

Biomass resources are used for food, feedstock, and energy. Food production is particularly responsible for most biodiversity loss, soil erosion and a large share of anthropogenic greenhouse gas emissions. The cultivation and processing of biomass (food and forest products) are now responsible for almost 90 per cent of global water stress and land-use-related biodiversity loss. The environmental impacts of land use include the destruction of natural habitats and biodiversity loss, soil degradation and loss of other ecosystem services. By the worldwide assessment made in 2010, it was found that land use had caused a loss of global species of approximately 11 per cent. Biomass extraction and processing also accounted for more than 30 per cent of the resource-related greenhouse gas emissions (neglecting land-use change) (Global Resources Outlook[12] , 2019).

[11] Schellnhuber, H.J., Rahmstorf, G., and Winkelmann, R. (2016) – Why the right climate target was agreed in Paris. *Nature Climate Change*, 6: 649-653.

[12] Global Resources Outlook (2019) – United Nations Environment Programme, Paris, 162 pg.

As it is understood, given the ecological, and social differences and resources in the world, the acuity of the problems briefly mentioned is not identical, just as the effects of climate change are fundamentally different from those that are most impacting on the agricultural systems such as soil quality, temperature, and rainfall.

Closely related to the issues of food security - understood "*as people always having physical, social and economic access to sufficient, safe, and nutritious food which meets their dietary needs for an active and healthy life regardless of the food's origin and the conditions under which it is produced and distributed*" (FAO[13], 2020) – are the questions related with food sovereignty that relegates for sovereign countries the responsibility to draw national policies they deemed fit for their citizens (UK Food Group [14], 2010). The latter requires that production be sustainable, just, and most importantly, local, guaranteeing universal access to available products.

Food sovereignty (Gordillo[15], 2013) enhances community control of resources and workers and supports climate and resource-friendly techniques, local distribution channels, and the social protection of small and medium producers. This is particularly crucial given the already mentioned rapid population growth and international corporations' extensive agriculture world land grabbing. In contrast to increasingly corporate-controlled systems and corporate-driven plant breeding, food sovereignty devolves more responsibility power to farmers, food workers, consumers, and citizens and "*places emphasis on accountability and democratizing food and nutrition policies at the village, municipal, national and international levels – through a rights-based approached and an emphasis on the right to food and nutrition framework*" (UK Food Group[16], 2010).

Failure of global food systems to address structural issues, such as poverty, deprivation, and marginalization, is a tremendous structural cause of malnutrition. Comprehensive global assessments and panels of experts have recently highlighted overwhelming evidence to advise a significant transformation of our food systems. Increasing urbanization, combined with the reorientation of urban agriculture and peri-urban lands towards more profitable uses, has gradually led to a "geographical decoupling" of areas of food supply sources, posing higher risks to food and nutritional security. The absence of specific food systems planning across the rural-urban continuum negatively impacts food and nutritional security in countries. Influential studies have revealed the dangerous condition of long-chain industrial food systems, from large-scale degradation of ecosystems and agricultural biodiversity and dangerously high greenhouse gas (GHG) emission levels to the precariousness of plantation workers and small food producers' livelihoods (IPES-Food[17], 2017; FAO[18], 2021;CWFS[19], 2022).

2 - Understanding the food system

The food system encompasses multidimensional activities related to i) availability, accessibility, stability, and utilization; ii) the outcomes of these activities to food security. The

---

[13] FAO, (2020) – Food Security Statistic [online: https://www.fao.org/ess-fs/en/]

[14] UK Food Group (2010) Securing future food: towards ecological food provision, UKFG: London, UK

[15] Gordillo, G. (2013) - Food Security and Sovereignty. FAO, 2013. [online: http://www.fao.org/3/a-ax736e.pdf].

[16] UK Food Group (2010) – Securing future food towards ecological food provisions. UKFG, London UK

[17] IPES-Food (2017) Unravelling the Food-Health Nexus, Addressing Practices, Political Economy, and Power Relations to Build Healthier Food Systems, IPES-Food, October 2017

[18] FAO, CIHEAM and UfM. (2021) - *Food systems transformation – processes and pathways in the Mediterranean: A stocktaking exercise.* Rome, FAO, 44 pp

[19] CWFS (2022) – Making a Difference in Food Security and Nutrition. Committee on World Food Security, 5th Session, 10-13 October

outcomes also contribute to the levels of environmental neutrality and other securities concerned, such as incomes and welfare livelihoods of people.

As recognized by FAO[20] (2018), agriculture, including fisheries and forestry, is far from being sustainable. Much of humanity's progress has come at a considerable cost to the environment. To produce more food and other non-food agricultural goods, a combination of intensified agricultural production processes and the clearing of forests has led to the degradation of natural resources and is contributing to climate change. Should we continue to address these challenges with a "business as usual" approach, the future will not look promising.

Due to increased agricultural production and unsustainable practices, the demand for land may exceed its available supply that is most suitable and unprotected for rainfed crops, as is already the case in specific regions such as the Mediterranean basin and those located in the Near East and North Africa, and even in some areas of Mediterranean Europe or selected countries in East Asia and the Pacific. This has a high potential to lead to environmental problems or additional production costs due to using lower quality land and constructing of additional infrastructure. As evidenced by the conclusions of the FAO study (2018) on forecasts for the future of food and agriculture – Alternative pathways to 2050, the sustainable intensification of agricultural sectors can potentially lessen the pressure of demand for land while maintaining soil quality.

Existing food systems are incapable of meeting the well-being needs of humanity. Today, approximately 9% of the world's population experience hunger (FAO[21], 2023) and 30% experience malnutrition (WHO[22], 2023) while simultaneously unhealthy diets are the greatest threat to human health from lifestyle-related diseases. With the planet needing to feed and nourish an additional 1.2 billion people by 2040, tackling the issues surrounding food systems has become one of the most critical and complex challenges for humankind (Franzo[23] et al. 2022). This challenge must be met under increasingly challenging ecological, socioeconomic, and geopolitical conditions.

Worldwide studies of food production and demographic trends show that sustainable agricultural intensification is the key to saving land to reduce food vulnerability. However, sustainable food and agriculture systems cannot be achieved without significant additional efforts. Measured against the sustainability criteria, the current food systems fail: they are a major source of greenhouse gas emissions, nutrient loading, land degradation, water stress, and biodiversity loss. They increase the need for transport with the accompanying adverse environmental effects and promote the wastage of edible food. They lead to a loss of income for farmers and to the progressive disappearance of smallholders. Because of that, efficient, well-managed and sustainable food systems are seen as essential to stop hunger and malnutrition, protect the natural resources base and maintain its long-term production capacity (HLPE[24], 2014).

[20] FAO (2018) – The future of food and agriculture – Alternative pathways to 2050. FAO, Rome. 224 pp.

[21] FAO (2023) - The State of Food Security and Nutrition in the World. [https://www.fao.org /3/cc3017 en/cc3017en.pdf].

[22] WHO (2023) - Malnutrition. World Health Organization. [https://www.who.int/news-room/fact-sheets/detail/malnutrition].

[23] Franzo, J., Rudie, C., Sigman I., Grinspoon, S., Benton, T.G., Brown, M.E., Covic, N., Kathleen, F., Golden, C.D., et al. (2022) - Sustainable food systems and nutrition in the 21st century: a report from the 22nd annual Harvard Nutrition Obesity Symposium. *Am. J. Clin. Nutr*. 2022 115(1):18-33. [doi: 10.1093/ajcn/nqab315].

[24] HLPE – High Level Panel Experts (2014) – Food Losses and Waste in the Context of Sustainable Food Systems. FAO, Rome

According to Garnett[25] (2013), three perspectives are broadly emerging on achieving sustainable food security and food system sustainability: i) efficiency orientation focused on changing production patterns; ii) demand restraint focused on reducing excessive consumption; and iii) food system transformation that considers both production and consumption. These perspectives are neither rigid nor mutually exclusive. Drawing upon all three perspectives, a composite approach to tackling the food sustainability problem is needed.

Therefore, a comprehensive approach to tackling the issue of food and nutrition security requires: 1) taking into account the interconnectedness and interactions between the four food and nutrition security dimensions mentioned above (availability, access, utilization and stability); 2) integrating all the stages of the food chain, including food production, sourcing and distribution; and 3) ensuring multi-sectoral engagement and coordination of sectoral policies (e.g. agriculture, trade, health, education, nutrition) (UN-HLTF[26], 2011). Achieving sustainable food security requires a transition towards more sustainable food consumption patterns and diets. It also requires efforts on both sides of the food chain: production and consumption (Capone[27] et al., 2014).

The main challenge for a holistic approach encompassing agriculture knowledge, science and technology (AKST), as mentioned by the UN[28] (2008), is to provide a path for a sustainable increase in agriculture productivity. This knowledge must address the needs of small-scale farms in diverse ecosystems and create realistic opportunities for their development where the potential for improved area productivity is low and where climate change may have its most adverse consequences. Sustainable agricultural production can be established by expanding and extending local and formal AKST to develop and deploy cultivars adaptable to site-specific conditions; improving access to resources; improving soil, water and nutrient management and conservation under a perspective of circularity; pre and postharvest pest management; and increasing small-scale farm diversification.

Recent efforts have emphasized the need to bridge ecosystem and social approaches to food vulnerability. Because the distribution of outcomes of both systems is differentiated concerning its distribution across time and space, studies by Adger[29] (2006) and Nelson[30] et al. (2007) emphasize the importance of the holistic analysis of the adaptative capacity of food production system and social consequences. To bring this holistic approach to life, we must draw new policies to revitalise rural areas and draw better connections among producers and consumers alongside well-coordinated animal and health management systems. Similarly, coordinated infrastructures and logistics for optimized agriculture trade flows could go a long way in enhancing food security all around the Mediterranean basin.

---

[25] Garnett, Tara (2013) - Three Perspectives on Sustainable Food Security: Efficiency, Demand Restraint, Food System Transformation. What Role for LCA? *Journal of Cleaner Production*, 73: 10-18.

[26] UN-HLTF (2011) - Food and Nutrition Security: Comprehensive Framework for Action. Summary of the Updated Comprehensive Framework for Action (UCFA), New York (N.Y.), United Nations System High Level Task Force on Global Food Security (HLTF).

[27] Capone R., El Bilali, H., Debs, P., Cardone, G., and Driouech, N. (2014) – Food System Sustainability and Food Security: Connecting the Dots. J*ournal of Food Security*. 2 (1): 13-22.

[28] UN (2008) – High-Levell Task Force on the Global Food Crisis. A Comprehensive Framework for Action Report. United Nations, NY. 51 pp.

[29] Adger, W. N. (2006) – Vulnerability. Global Environmental Change 16(3): 268-281.

[30] Nelson, D. R., Adger, W. N. and Brown, K. (2007) – Adaptation to environmental change: contribution of a resilience framework. Annual Review of Environment and Resources 32: 395-419.

2 intends to depict these cascading interrelationships of climate change impacts on food security and nutrition, with potential consequences on social welfare, and environmental security/natural capital as well.

When these conditions change slightly, even in a direction that may seem favourable, the prevalent fauna and flora will be affected, becoming less productive or even disappearing. Some of these consequences can be easily predicted, such as the direct effect of a heat wave on a given crop at a given point in its growth cycle. Others, however, are more complex to predict, such as the effect of a given climate change on an entire ecosystem, as each element will react differently, which can be translated into decreases or increases in the yields of the cultivated plants.

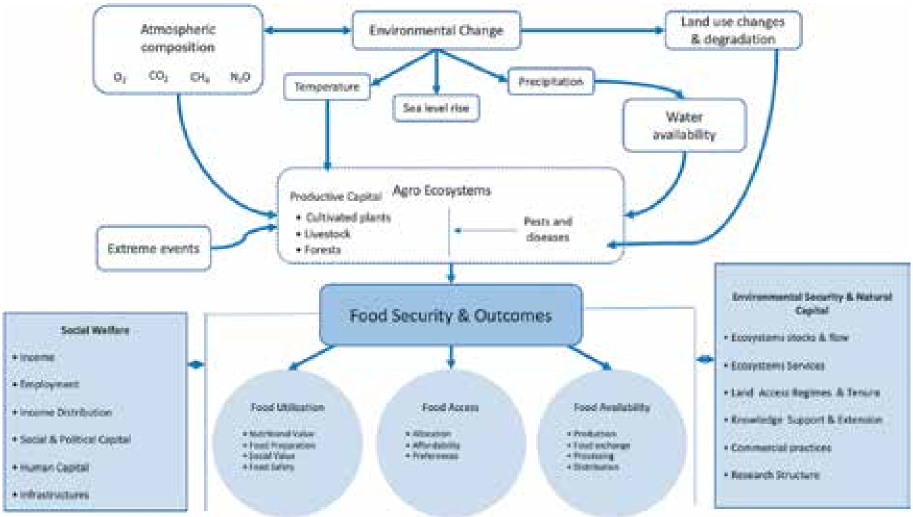


Fig. 2 - Multidimensional representation of the impacts of climate change

Pests and diseases are also likely to move following climate change, thus arriving in less prepared areas, potentially having higher negative impacts. The world witnessed 3455 floods, 2689 storms, 470 droughts and 395 extreme temperature events between 1980 and 2011 (UNISDR[31], 2012). More recently, the estimated costs of natural disasters recorded in 2021 by one of the global reinsurers, the Reinsurer Swiss Re, amounted to around 221 billion euros, an increase of 24% compared to 2020. As population increases especially in coastal areas, where most of the world's population now lives, meaning that more people will be affected by catastrophic weather events. Between 1970 and 2021, there were 11 778 reported disasters attributed to weather, climate and water extremes, causing over 2 million deaths and US$ 4.3 trillion in economic losses. Over 90% of these reported deaths and 60% of economic losses occurred in developing economies. The impacts of these extreme events lead to losses of lives and livelihoods, exacerbate poverty and inequality, amplify food and water insecurity, trigger economic instability and, ultimately, undermine sustainable development (WMO[32], 2023).

[31] UNISDR (2012) – Annual Report 2012. The United Nations Office for Disaster Risk Reduction, Geneva 52 pp.

[32] WMO (2023) - United in Science 2023. World Meteorologic Organization, Geneva, 47 pp.

Concern over the current and future harmful consequences of global environmental changes for food systems is motivated by the three intertwined narratives (Ericksen[33], 2008).

First, despite the technological and scientific advances made in the last centuries and international programmes to irradicate poverty (e.g. Millennium Development Programme 2000-2015), chronic food insecurity persists worldwide (Fig. 3 and Fig. 4). While estimates between 720 to 811 million people remain undernourished (as many as 161 million more than in 2019), the number affected by micronutrient deficiencies probably exceeds 2 billion (FAO, 2020).

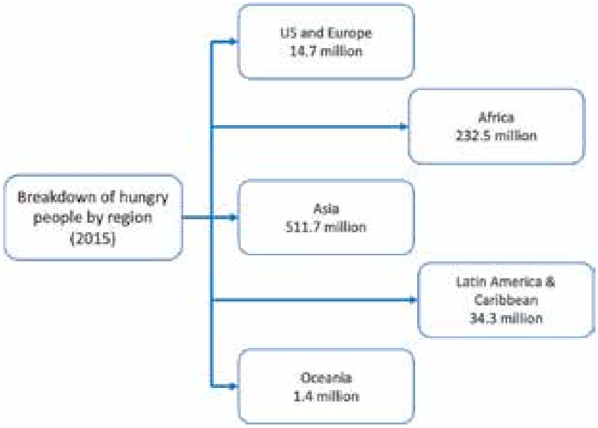


Fig. 3 - Hunger distribution in the world (FAO , 2020)

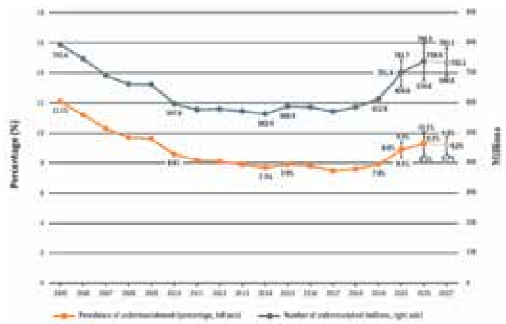


Fig. 4 - Worldwide trends of prevalence of undernourished people
Source: FAO[34], (2023)
(Note: projected values for 2022 are illustrated by doted lines and empty circles; Bars show lower and upper bounds of the estimated range.)

One must also mention that FAO[35] et al. (2021) estimate that nearly 2.37 billion people did not have access to adequate food in 2020 – an increase of 320 million people in just one year. We should also take hold that the COVID-19 pandemic exacerbated an already deteriorating

[33] Ericksen, R.J. 2008 – "What is the Vulnerability of a Food System to Global Environmental Change? Ecology and Society 13(2) [online: http://ecologyandsociety.org/vol13/iss2/art14].42 pp

[34] FAO (2023) – FAOSTAT: Suit of Food Security Indicators. [www.fao.org/faostat/en/#data/FS

[35] FAO, IFAD, UNICEF and WHO (2021) – The State of Food Security and Nutrition in the World 2021. Transforming Food Systems for Food Security, Improved Nutrition and Affordable Healthy Diet for All. 240 pp.

situation, with about 150 million more people facing hunger in 2021 than in 219 (UN[36], 2022). The most troublesome increases were seen in sub-Saharan Africa.

The unfolding crisis in Ukraine and Russia Federation, considered the world's breadbasket, supplying 30 % and 20% of global wheat and maize exports, respectively, and 80% of global sunflower seed product exports, is another threat to food security.

Second, events of the past decade have heightened awareness of the increasing impact of natural hazards on food, income, and environmental security, for which modern society has a widespread lack of holistic policies and preparedness.

Third, the assessment made by the Global Environment Outlook[37] (2019) concluded with certainty that the ecosystem services enabling food production systems are being eroded through changes in nutrient and hydrological cycles, vegetation cover, erosion, and pollution. Adding to this negative trend, predictions on future climate change raise expectations of the growing uncertainty that hangs over the future distribution of rainfall, temperature, and uncertainty in the predictability of its seasonal distribution on which agricultural activity strongly depends.

Looking for direct causes of poverty, undernourishment, and hunger persistence, we must remember that over the past five decades, our global population has doubled, and materials extraction has tripled, even though the gross domestic product has quadrupled. The extraction and processing of natural resources have accelerated over the last two decades, accounting for more than 90 per cent of our biodiversity loss, water stress and approximately half of our climate change impact. The degradation of ecosystem services is already a significant barrier to achieving the Sustainable Development Goals (SDG) agreed upon by the international community in 2015. Over these last 50 years, we have not once experienced a prolonged period of stabilization or a decline in global material demand.

The causes of this food insecurity are complex and the probability to achieve zero hunger by 2030 as declared by SDGs, is almost unattainable. Truly the hopeful downward trends that have been manifested with the implementation of the Millennium Development Goals (MDG) have been reversed (Fig. 4), with worrying increases mainly in Asia and African countries (Fig. 5).

Demographic and changes in consumption patterns, poor harvesting practices, as well as food wastage have contributed to food scarcity. Wars have also had a negative impact on the availability of food and have led to the destruction of the environment, which is critical to growing food.

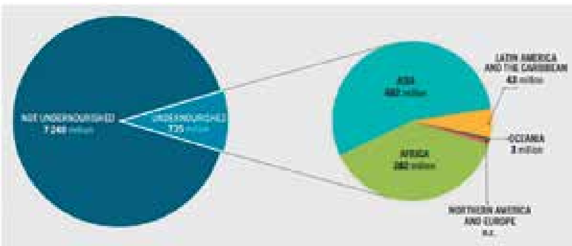


Fig. 5 - World distribution of prevalent undernourished people (FAO, 2023)

[36] UN (2022) – The Sustainable Development Goals Report 2022. United Nations, Dept. of Economic and Social Affairs (DESA), NY. 65 pp.

[37] Global Environment Outlook GEO6. (2019) - Heathy Planet, Healthy People. Cambridge University Press. 745 pg.

Food security and agriculture development are today's significant strategic challenges for the planet. In the eyes of public opinion and the laymen, the 2008 and 2022 food crises revealed the centrality of agriculture and food issues in global strategic affairs. However, if the economic situation sometimes increases political vigilance towards them, it is essential to remember that the food imperative has always imposed itself almost everywhere. Undoubtedly due to food and climate constraints at times and in specific geographies aggravated by demographic pressures, these issues now take on a more structural dimension. The urgency of delineating and structural measures in agriculture, land use planning and the unified management of the landscape is an urgent imperative and priority for countries and regions particularly subject to the vagaries of the climate as happens throughout the Mediterranean coast including Portugal.

In summary, despite achieving the most progress in reducing undernourishment, Asia is currently home to more than 55 per cent of the undernourished people globally. Africa has the highest prevalence of undernourishment (PoU) and the second-highest number of undernourished people, accounting for 36.4 per cent of the global total. A much smaller share is seen in Latin America and the Caribbean (almost 7 per cent), and an even smaller share in Oceania and other regions. If recent trends persist, the distribution of hunger in the world will change substantially, making Africa the region with the highest number of undernourished people in 2030 (FAO, 2020).

As mentioned above, climate change directly impacts the agroecosystems, which in turn affects agricultural production, driving economic and social effects on livelihoods and food security. In other words, each impact of each climate parameter is reflected in the productive sphere and the economic and social dimensions. At each stage of this stress transmission chain, the shocks are determined by the shock itself and vulnerability at the stage/level of the stressed system. The transmission of a stress can be amplified or reduced depending on the vulnerabilities at each system level. Vulnerability can increase over time if systems/households face repeated shocks that steadily erode their base/assets. These mechanisms of transmission and the role played by the various vulnerabilities at each level, are what determine the final impact on food security and nutrition.

The IPCC, in its synthesis report (IPCC[38], 2014a) notes that exposure and vulnerability are influenced by a wide range of social and economic factors and processes that have been incompletely considered to date, which make quantitative assessments difficult or impossible. It also notes that climate-related hazards exacerbate other stressors, which often result in negative outcomes for livelihoods, especially for people living in poverty. Both biophysical and social vulnerability are thus critical as one considers the impact of climate change on food security. A social vulnerability lens is essential to understand why certain individuals, households, or communities experience differences in effects even when they are in the same geographic region.

Worldwide studies realized on trends on food production, show that to reduce food vulnerability, a sustainable agricultural intensification is key to saving land. Due to increasing agricultural production and unsustainable practices, the demand for land might exceed the available reserve of very suitable and unprotected land for rainfed crops, as is already the case in specific regions such as the Near East and North Africa, or in selected countries in East Asia and the Pacific. This could entail environmental problems or additional production costs from using lower-quality land and/or building additional infrastructures. As shown by the findings of this

[38] IPCC. 2014a. *Climate change 2014: synthesis report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Core Writing Team, R.K. Pachauri & L.A. Meyer, eds. Geneva, Switzerland, IPCC. 151 pp.

report, the sustainable intensification of agricultural sectors can potentially lower the expansion of demand for land while maintaining soil quality.

Seeking an ecologically sustainable and socially fair transition out of the current crisis has become an issue of utmost priority. Multiple voices have called for a paradigm shift in the structure and operation of the global food system although the values, narratives, economic and moral foundations of that new aspirational and inspirational paradigm have not yet been fully developed (Vivero-Pol[39], 2017). Applying system thinking to understand and manage the complexity of the global eco-agri-food system is essential in achieving this transformation (UNEP[40] 2011). By making the externalities (invisible) visible, society will be better positioned to consider the impacts of activities that have previously been ignored. Hidden costs of global agri-food systems worth at least $10 trillion (FAOa[41], 2023).

The knowledge available today makes it possible to state that achieving productive improvements in sustainable food systems and carbon neutrality in food production is unachievable unless the necessary transformations to achieve sustainable productivity improvements are supported by adequate investments and technical changes in food systems and agriculture. They question whether the future demand for agricultural products will be compatible with the urgent need for greater sustainability in the use of resources. To meet the growing demand for farm products more sustainably, food and farming systems need more investment in research and development to drive technical change. This is especially true for regions that currently lag in productivity and are among the most food insecure, such as sub-Saharan Africa. As funding for investment is a limited asset, it is critical that research objectively identify priorities for achieving sustainable productivity improvements in social, environmental and economic terms.

Concerning carbon neutrality, data show that unaddressed climate change increasingly affects agricultural income and rural livelihoods. At the same time, food and farming systems and the economy continue to emit GHGs. This puts pressure on natural resources and changes the distribution of what can be produced and where. The fact that GHGs from human activities are the most significant driver of observed climate change since the mid-20th century, achieving carbon neutrality without profoundly altering agricultural systems is problematic.

Food and agricultural systems are among the critical contributors to GHG emissions and are crucial to climate change mitigation efforts. So far, GHG emissions within the economy have not been significantly reduced. Changes in agricultural production systems aimed at mitigating and adapting to climate change are expected to impact all food systems positively.

Therefore, understanding food-security vulnerability to climate change is critical to understanding net climate sways on food security and framing ways to adapt to climate risks to draw the means to reduce the net climate change impact on food systems.

---

[39] Vivero-Pol, J.L. (2017) - Conclusion: Towards a more just and flexible global food system. In: *Food systems failure: The global food crisis and the future of agriculture.* (Ed.) Rosin, C., Stock, P., and Campbell, H. New York, NY: Earthscan

[40] UN Environment Programme (UNEP) (2011) - Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication. Nairobi: UNEP.

[41] FAOa (2023) – The State of Food and Agriculture. Revealing the True Cost of Food to Transform Agrifood Systems. Rome. 121 pp.

3 - Topics on GHGs emissions

Evidence from observations of the climate system and global climate model experiments has led to the conclusion that human activities are contributing to a warming of the earth's atmosphere (IPCC[42] 2007a). Human activities – primarily burning of fossil fuels and changes in land cover – are modifying the concentration of atmospheric constituents or properties of the Earth's surface that absorb or scatter radiant energy. Increases in the concentrations of greenhouse gases (GHGs) and aerosols are strongly implicated as contributors to climatic changes observed during the twentieth century and are expected to contribute to further changes in climate in the twenty-first century and beyond.

Greenhouse gases allow solar radiation to reach the Earth unhindered but trap a proportion of outgoing radiation playing thereby a critical role in maintaining the Earth's heat balance. But as GHGs concentrations rise, radiative net fluxes change, with an increase of infrared radiation which induces atmosphere warming (e.g. Stull[43], 2000). In this context, a fundamental concept for assessing the degree of climate change is the so-called radiative forcing (RF[*]) (e.g. IPCC 2013). This metric has been used for many years by IPCC to evaluate the strength of the various mechanisms affecting the Earth's radiation balance. Aerosols partially offset the forcing of the effects of greenhouse gases and dominate the uncertainty associated with the total anthropogenic driving of climate change. Emissions of CO_2 have made the largest contribution to the increased anthropogenic radiative forcing in every decade since the 1960s.

Atmospheric emission of greenhouse gases (GHG) has steadily increased since the Industrial Revolution and global trends are indicative of the imbalance between sources and sinks in the gas budgets and are strictly related to atmospheric emissions on a global scale. The total anthropogenic radiative forcing for 2011 relative to 1750 is 2.29 [1.13 to 3.33] Wm^{-2}, and it has increased more rapidly since 1970 than during prior decades. The total anthropogenic RF best estimate for 2011 is 43 % higher than that reported in AR4 for the year 2005 (IPPC[44], 2013). This is caused by a combination of continued growth in most greenhouse gas concentrations and improved estimates of RF by aerosols indicating a weaker net cooling effect (negative RF).

Time-dependent correlations of reconstructions with time-series records representing changes in GHG concentrations show that greenhouse gases are the dominant radiative forcing during

---

[42] IPCC (2007a) Climate change 2007: synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the intergovernmental panel on climate change. In: Core Writing Team, Pachauri RK, Reisinger A (eds). IPCC, Geneva

[43] Stull, R (2000) – Meteorology for Scientists and Engineers, 2nd ed. Brooks/Cole, Thomson Learning. 502 pp.

[*] Radiative forcing happens when the amount of energy that enters the Earth's atmosphere differs from the amount of energy that leaves it. Energy travels in the form of radiation: solar radiation entering the atmosphere from the sun and infrared radiation exiting as heat. If more radiation is entering Earth than leaving—as is happening today—then the atmosphere will warm up. This is called radiative forcing because the difference in energy can force changes in the Earth's climate.

[44] IPCC (2013) - Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, 1535 pp.

the 20th century (Mann *et al.*[45], 1998). Global climate change takes place when the earth-atmosphere system responds to counteract radiation flux changes.

Among the gases targeted by the Kyoto Protocol are: (i) carbon dioxide, which is emitted to the atmosphere through burning solid waste, fossil fuels such coal, natural gas, and oil, burning of woody and non-woody biomass, wood products, and agricultural residues, and because of certain chemical reactions (e.g. manufacture of cement). Carbon dioxide is sequestered from the atmosphere, e.g. when it is absorbed by plant photosynthesis as part of the biological carbon cycle; (ii) methane, which is emitted, among other sources, through livestock and other agricultural practices, the decay of organic waste in municipal solid waste landfills or the production and transport of coal, natural gas, and oil; (iii) nitrous oxide (N_2O) which is emitted through combustion of fossil fuels and solid waste and from agricultural and industrial activities; fluorinated gases such as hydrofluorocarbons, perfluorocarbons, sulphur-hexafluoride, and nitrogen trifluoride, which are powerful synthetic greenhouse gases that are emitted from a variety of industrial processes. These gases are typically emitted in smaller quantities. Still, because they are potent greenhouse gases, they can be referred to as High Global Warming Potential Gases (HGWPG), e.g. EPA[46], 2017.

Anthropogenic atmospheric emissions of greenhouse gases (GHG) have continuously increased since the 19th century, and with them, the Earth's temperature. In 2018, greenhouse gas concentrations reached new peaks, with global average molar fractions of carbon dioxide (CO_2) at 407.8 ± 0.1 parts per million (ppm), methane (CH_4) at 1869 ± 2 parts per billion (ppb) and nitrous oxide (N_2O) at 331.1 ± 0.1ppb. These values constitute 147 %, 259 % and 123 % of the pre-industrial levels 1750 (Climainfo[47], 2019). Hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) all continue to increase relatively rapidly, but their contributions to radiative forcing are less than 1 % of the total GHGs.

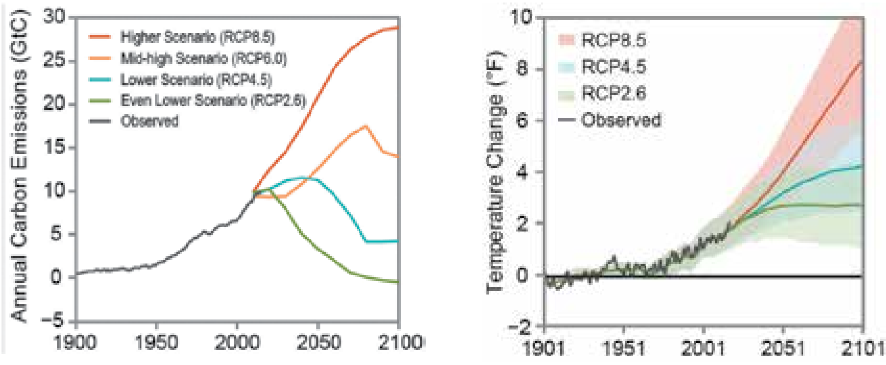
Global climate is projected to continue to change over this century and beyond. The magnitude of climate change beyond the next few decades will depend primarily on the amount of greenhouse (heat-trapping) gases emitted globally and on the remaining uncertainty in the sensitivity of Earth’s climate to those emissions (very high confidence). With significant reductions in the emissions of greenhouse gases, the global annual average temperature rise could be limited to 2°C or less. Without major reductions in these emissions, the increase in annual average global temperatures relative to preindustrial times could reach 5°C or more by the end of this century (Fig. 6).

---

[45] Mann, M. E., Raymond, S.B., Hughes, M. H. (1998) – Global-scale temperature patterns and climate forcing over the past six centuries. *Nature*, 392: 779-787.

[46] EPA (2017) – Sources of Greenhouse Gases. U.S. Environmental Protection Agency.

[47] Climainfo – 2019 Conclui uma Década de Aquecimento Global Excecional. [access: https://climainfo.org.br/2019/12/03/2019-conclui-uma-decada-de-aquecimento-global-excepcional-e-clima-de-alto-impacto]



a) b)

Fig. 6 - a) Projected annual carbon emissions; b) Projected global temperatures
Data from: Wuebbles[48], et al. (2017)

When global leaders convened in Paris in 2015, they agreed to cut their greenhouse emissions enough to try and limit global warming to 1.5 °C. Yet as they gather again at the United Nations' COP26 (2021) climate meetings in Glasgow, they are not even close to meeting that target. Emissions have bounced back after falling during the height of the COVID-19 pandemic, and atmospheric carbon dioxide levels are the highest they have been in human history. They now measure about 40% above their pre-industrial levels (https://bit.ly/3nyOa0t). These increases in greenhouse gas emissions have substantially enhanced both the greenhouse effect and the radiative forcing. Despite that countries participating in COP27 (2022) recognised the low path of CO_2 abatement, they reiterated the Paris Agreement goals of keeping temperature increases to well below 2 ºC, meaning the recognition to the need to achieve reductions in global greenhouse gas emissions of 43% by 2030 relative to the 2019 level; it also recognized the need to enhance energy security by accelerating clean and just transitions; and stressed the need for low-emission and renewable energy.

Indeed, IPPC's AR4 concluded that increasing atmospheric burdens of well-mixed GHGs resulted in a 9 % increase in their RF from 1998 to 2005 and a further increase of 7.5 % in the period between 2005 to 2011, with carbon dioxide (CO_2) contributing 80 % (Hartmann et al., 2013).

Another IPCC document, the Special Report on Emissions Scenarios (SRES, 2000), projected increased global GHG emissions by 25 to 90 % (CO_2eq) between 2000 and 2030, with fossil fuels maintaining their dominant position in the global energy mix to 2030 and beyond. For the two decades since 2007, a warming of about 0.2 °C per decade was projected. Even if all GHGs and aerosols concentrations were kept constant at the 2000 levels, further warming of about 0.1 °C per decade would be expected.

Agriculture has a strong relationship with climate change because of its effects on agricultural activities and contribution to GHG transfers and carbon sequestration. Because of agriculture's sensitivity to climate change, different countries are increasingly assessing accurate projections of likely changes to effectively support preventive and mitigating measures that safeguard their

[48] Wuebbles, D.J., Fahey, D.W.., Hibbard, K.A., Dokken, D.J., Stewrt, B.C. and Maycock, T.K. (eds) (2017) - *Climate Science Special Report: Fourth National Climate Assessment, Volume I.* U.S. Global Change Research Program, Washington, DC, USA, 470 pp., [doi: 10.7930/J0J964J6]

food production systems, as well as of their farmers, who are enormously impacted on their revenues and, more importantly, on their food security.

4 - Brief reference on numeric modelling for climate change assessment

Climate change projections are a very complex phenomenon, dependent on a myriad of interacting factors controlling air temperatures such as solar output, earth orbital characteristics, ocean and atmosphere circulations, clouds, ice and snow, plate tectonics, natural and anthropogenic gases, particulates, and aerosols (Stull[49], 2000). It is even more complex when regionally downscaled to the Mediterranean basin. These factors are considered positive or negative feedback if they amplify or reduce climate change. Experimentation on climate change is possible with a particular class of large-scale, long-duration numerical weather forecast complex models known as Global Circulation Models (GCM) (IPCC, 2007 (AR4 and AR5); Stull, 2000). GCM climate simulations have greatly improved the understanding of atmospheric physics, feedback processes and climate sensitivities.

The complex simulation processes mentioned above, such as sea ice melting and water vapour formation increase due to heating, are duly considered. However, many approximations of the input variables are needed to run these models, and climate change predictions are still somewhat uncertain. These feedback processes include numerical models through physical or thermodynamic equations; others are approximated or parameterized. The new models developed by the Coupled Model Intercomparison Project Phase 6 (CMIP6) of the World Climate Research Programme include new and better representation of physical, chemical, and biological processes, as well as higher resolution, compared to climate models considered in previous IPCC assessment reports. This has improved the simulation of the recent mean state of most large-scale indicators of climate change and many other aspects across the climate system. Some differences from observations remain, for example in regional precipitation patterns.

The new CMIP6 historical simulations have an ensemble mean global surface temperature change within 0.2°C of the observations over most of the historical period, and observed warming is within the very likely range of the CMIP6 ensemble. However, some CMIP6 models simulate a warming that is either above or below the assessed very likely range of observed warming. These CMIP6 models also show a higher average climate sensitivity than CMIP5 and the AR6 assessed best estimate. The higher CMIP6 climate sensitivity values compared to CMIP5 can be traced to an amplifying cloud feedback that is larger in CMIP6 by about 20 % (IPCC[50], 2021).

Despite these remaining uncertainties, the final models can successfully study complex interactions in atmospheric circulation and signal trends that guide adaptation and mitigation actions.

---

[49] Stull, R. (2000) – Meteorology for Scientists and Engineers, 2nd ed. Brooks/Cole, Thomson Learning, 502 pp.

[50] IPCC (2021) - Summary for Policymakers. In: Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A. Pirani, S. L. Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. Matthews, T. K. Maycock, T. Waterfield, O. Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. In Press.

Climate oscillations and associated meteorological events are stochastic, non-linear, and frequently thermodynamically irreversible, and GCMs and RCMs still present substantial uncertainties for accurately characterizing these events. Excessive parameterization of variables to improve approximations to nature can compromise the forecast quality of GCMs. Cascading effects propagate through the earth-atmosphere system following biophysical responses to disrupting the net radiation anomalous changes. All climate models have still now several limitations. The coarse resolution of global climate models does not adequately depict many geographic features and the interactions between the atmosphere and the land surface. Natural variations in local climate are much greater than those in climate averaged over continental or larger scales. Few model experiments have taken aerosols into account, and those that do include only very simplified effects so that the uneven spatial impact is not adequately dealt with. In addition, land-use changes such as deforestation and desertification are currently seldom allowed for but are expected to affect local climates substantially.

Besides these uncertainties, it should be said that the values used for rainfall and temperature to make projections of future land conditions lack accurate information on the earth's surface, as mentioned by Berg[51] and McColls (2021). New models being developed to tackle this problem are now integrating both atmospheric and land conditions. As those authors say, "*if you want to know if the land is going to get drier, if crops are going to fail or if a forest is going to dry out, you must look at the land itself*". As the climate is warming, there is a divergence between atmospheric and land surface behaviour. To account for that divergence, Berg and McColls (2021) are developing a new metric for drylands, based on land surface properties, including biological responses to higher atmospheric CO_2, for comparing dry land projection to those derived solely from atmospheric metrics and furthering research efforts in developing more accurate land surfaces models.

Although with a margin of incertitude, GCM climate simulations have greatly improved the understanding of atmospheric physics, feedback processes and climate sensitivities and is now an essential tool to support the intervention and mitigation policies in the agrarian sector to make it more neutral to its high CO_2 emitting load.

4.1 - Alternative scenarios for climate change predictions

The temperature projections increasingly depend on a range of emission scenarios. The IPPC (AR4) established four climate change scenarios, which were the B1, AIT, B2, A1B, A2 and A1FI, (e.g. IPPC AR4) corresponding to concentrations of GHG (CO_2eq), in 2100 of 600, 700, 800, 850, 1250 and 1550 ppm, respectively.

The six scenarios were based on four scenario families (A1, A2, B1 and B2) (Table 1) that assume alternative socio-economic development roadmaps, covering a wide range of demographic, economic and technological driving forces and the resulting GHG emissions. These underlying socio-economic assumptions serve as inputs to many current assessments of climate change vulnerability and impact and do not assume additional climate policies besides the current ones.

---

[51] Berg, K.A. and McColls (2021) – No projected climate global dryland expansion under greenhouse warming. *Nature Climate Change* 11: 331-337

Table 1 – Four SRES scenarios according to sustainability and globalization dimensions

Material intensity development
Focused on strong economic growth

A1			**A2**
Food trade	Maximal	Food trade	Low
Meat consumption	High	Meat consumption	High
Technological development	High	Technological development	Low
Crop Intensity growth	High	Crop Intensity growth	Low
Population	2050: 8.7 billion 2100: 7.1 billion	Population	2050: 11.3 billion 2100: 15.1 billion
GDP	529 trillion $\$_{95}Y^{-1}$	GDP	243 trillion $\$_{95}Y^{-1}$
Global orientation			**Regional orientation**
Food trade	High	Food trade	Very low
Meat consumption	Low	Meat consumption	Low
Technological development	High	Technological development	Low
Crop Intensity growth	High	Crop Intensity growth	Low
Population	2050: 8.7 billion 2100: 7.1 billion	Population	2050: 9.4 billion 2010: 10.4 billion
GDP	328 trillion $\$_{95}Y^{-1}$	GDP	235 trillion $\$_{95}Y^{-1}$
B1			**B2**

Development focusing on sustainable values

Source: Hoogwijk[52] et al. (2005)

The A1 pathway corresponds to a business-as-usual situation. It entails a global high economic growth with a global population peaking in the mid-21st century and a fast introduction of new efficient technologies. A1 is divided into three groups with distinct directions of technological change: fossil intensive (A1FI), non-fossil energy resources (A1T) and a balance across all sources (A1B). B1 entails the lowest emissions, describes a convergent world, with the same global population as A1, but with faster changes in global economy agents towards a service and information economy. B2 describes a world with a medium-level population and economic growth, emphasizing local economic, social, and environmental sustainability policies. A2 describes a very heterogeneous world with high population growth, slow economic development, and slow technological change. No likelihood has been attached to any of these scenarios.

This range of projections under AR4 is broadly consistent with the Third Assessment Report (TAR). Still, uncertainties and upper ranges for temperature are larger mainly because the broader range of available models suggests stronger climate-carbon cycle feedback. Warming reduces terrestrial and ocean uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions remaining in the atmosphere. The strength of this feedback effect varies markedly

[52] Hoogwijk, M., Faaij, A., Eickhout, B., de Vries, B. and Turkenburg, W. (2005) – Potential of biomass energy out to 2100, for four IPCC SRES land-use scenarios. *Biomass and Bioenergy*, 29: 225-257.

among models. An accurate assessment of the rise of the sea is still restricted by the knowledge and understanding of some significant effects driving sea level rise.

The temperature changes estimated under these scenarios, comparing the periods 2090-2099 and 1980-1999 are 1.8 °C, 2.4 °C, 2.4 °C, 2.8 °C 3.4 °C, respectively. The sea-level rise estimated (Model-based excluding future rapid dynamical changes in ice flow) under these scenarios and comparing the same periods' range in the intervals of 0.18 m – 0.38 m, 0.20 m – 0.45 m, 0.20 m – 0.43m, 0.21 m – 0.48 m, 0.23 m – 0.51m and 0.26 m – 0.59 m, respectively.

New projections (IPCC, AR5) of changes in the climate system are made using models of increased and more comprehensively complex. These models simulate changes based on a set of scenarios of anthropogenic forcing's. More recently, a new set of scenarios was used for the new climate model simulations carried out under the framework of the Coupled Model Intercomparison Project Phase 5 (CMIP5) of the World Climate Research Programme based on Representative Concentration Pathway (RCPs) scenarios of atmospheric CO_2 concentrations that were consistent with a wide range of possible changes in future anthropogenic GHG emissions and aimed to represent their atmospheric concentrations.

The Representative Concentration Pathways (RCPs) are a set of possible climate scenarios for the end of the century. The RCPs were used extensively in the 2014 IPCC Fifth Assessment Report but lack a consistent set of socio-economic assumptions driving future emissions and are intended to reflect different potential climate outcomes (van Vuuren[53] et al., 2011). They include RCP1.9, RCP2.6, RCP4.5, RCP6.0 and RCP8.5, with the number reflecting the additional radiative forcing in 2100, relative to pre-industrial times. Radiative forcing (in Wm^{-2}) measures the combined effect of greenhouse gas emissions and other factors (such as atmospheric aerosol levels) on climate warming. It represents the net change in the energy balance of the Earth system due to some imposed perturbation. Current radiative forcing relative to pre-industrial levels is around 2.5 Wm^{-2}.

The RCPs limits were defined as to cover the range provided by the literature review with the scenarios that can be found for the year 2100 radiative forcing from as low as 2.5 W/m^{-2} to between 8 and 9 W/m^{-2} and higher (van Vuuren et al., 2011). It also includes scenarios to intermediate forcing levels found in the literature. It also includes scenarios for intermediate forcing levels found in the literature. These scenarios were defined so that they were sufficiently separated (by about 2 Wm^{-2}) concerning radiative forcing pathways to provide distinguishable climate results. The scenarios considered (AR5) were:

RCP 1.9 is a pathway that limits global temperature to below 1.5 °C, the aspirational goal of the Paris Agreement.

RCP 2.6 is a "very stringent" pathway. It foresees a peak in radiative forcing at ~3Wm^{-2} (~ 490 ppm CO_2 eq.) before 2100 and then decline (the selected pathway decreases to 2.6 Wm-2 by 2100. According to the IPCC, RCP 2.6 requires carbon dioxide (CO_2) emissions to decline by 2020 reaching zero by 2100. It also requires that methane (CH4) go to approximately half the CH_4 levels of 2020 and that Sulphur dioxide (SO_2) emissions decrease to approximately 10% in the 1980 – 1990 period. Like all the other RCPs, RCP 2.6 requires negative CO_2 emissions (i.e. CO_2 absorption

---

[53] van Vuuren, Detlef P., Edmonds, J., Kainuma, Mikiko, Riahi, K., Thomson, A., Hibbard, Kathy, Hurtt, G.C., Kram, Ton et al. (2011) – The representative concentration pathways: an overview. *Climate Change* 109: 5-31

by trees). For RCP 2.6, those negative emissions would be 2 $GtCO_2yr^{-1}$). It is foreseen the RCP 2.6 is likely to keep global temperature rise below 2 °C by 2100.

RCP 3.4 represents an intermediate pathway between the "very stringent" RCP2.6 and less stringent mitigation efforts associated with RCP4.5. Another variant option of RCP3.4 includes the considerable removal of greenhouse gases from the atmosphere.

A 2021 paper suggests that the most plausible projections of cumulative CO_2 emissions (having a 0.1 % or 0.3 % tolerance with historical accuracy) tend to indicate that RCP 3.4 (3.4 W/m^{-2}, 2.0 - 2.4 °C warming by 2100 according to study) as the most plausible pathway.

RCP 4.5 is described by the IPCC as an intermediate scenario in which the emissions will stabilize without overshoot pathway to 4.5 Wm^{-2} (~ 650 ppm CO_2 eq) at stabilization after 2100. Emissions in RCP 4.5 peak around 2040, then decline.

According to the IPCC, RCP 4.5 requires that carbon dioxide (CO_2) emissions start declining by approximately 2045 to reach roughly half of the levels of 2050 by 2100. It also requires that methane emissions (CH_4) stop increasing by 2050 and decrease somewhat to about 75 % of the CH_4 levels of 2040 and that Sulphur dioxide (SO_2) emissions decline to approximately 20 % of those of 1980 -1990. Like all the other RCPs, RCP 4.5 requires negative CO_2 emissions (such as CO_2 absorption by trees).

For RCP 4.5, those negative emissions would be about 2 $GtCO_2$ yr-1. RCP 4.5 is more likely than not to result in a global temperature rise between 2 °C and 3 °C, by 2100, with a mean sea level rise 35% higher than RCP 2.6. Many plant and animal species will be unable to adapt to the effects of RCP 4.5 and higher RCPs.

RCP 7 is a baseline outcome rather than a mitigation target.

In RCP 8.5, the rising radiative forcing pathway peaked at 8.5 Wm^{-2} (~1370 ppm CO_2 eq. by 2100). In this scenario, emissions continue to increase throughout the 21st century. Since AR5, this has been thought to be very unlikely, but still possible as feedback is poorly understood. RCP8.5 is generally taken as the basis for worst-case climate-change scenarios. It was based on what proved to be an overestimation of projected fuel, mostly coal, outputs. The RCP8.5 scenario may be relatively unlikely, with one report (Hausfather[54] and Peters, 2020) mentioning it an "*increasingly implausible with each passing year*". RCP8.5 remains, however, useful for its aptness in tracking historical total cumulative CO_2 emissions and predicting mid-century (and earlier) emissions based on current and stated policies.

Predictions expressed by RCP's scenarios show that relative to 1850-1900, global surface temperature change for the end of the 21st century (2081-2100) is projected to *likely* exceed 1.5 °C for RCP4.5, RCP6.0 and RCP8.5 (*high confidence*). Warming is *likely* to exceed 2 °C for RCP6.0 and RCP8.5 (*high confidence*), *more likely than not* to exceed 2°C for RCP4.5 (*medium confidence*), but *unlikely* to exceed 2 °C for RCP2.6 (*medium confidence*).

Despite characterizing RCPs in terms of inputs, a key change from 2007 to the 2014 IPCC report is the criticism that the RCPs ignore GHG emissions by focusing on concentrations of greenhouse gases inputs. The IPCC studies the carbon cycle separately, predicting higher ocean uptake of carbon corresponding to higher concentration pathways. Concerning land carbon

[54] Hausfather, Zeke; Peters, Glen (29 January 2020). Emissions – the business-as-usual story is misleading. *Nature*. 577 (7792): 618-20. doi:10.1038/d41586-020-00177-3

uptake, it founds it is much more uncertain due to the combined effect of climate change and land-use changes.

As in previous IPCC assessments, AR5 uses the radiative forcing (RF) concept and introduces the concept of effective radiative forcing (ERF). Whereas in the RF concept, all surface and troposphere conditions are kept fixed, the ERF calculations allow all physical variables to respond to perturbations, except for those concerning the ocean and sea ice. The inclusion of these adjustments makes ERF a better indicator of the eventual temperature response. ERF and RF values are significantly different for anthropogenic aerosols due to their influence on clouds and snow cover. These changes to clouds are rapid adjustments and occur on a time scale much faster than responses of the ocean (even the upper layer) to radiate forcing. The total anthropogenic ERF estimates for 2011 was 43% higher compared to the AR4 RF estimate for the year 2005, owing to continued growth in greenhouse gas RF and reductions in estimated radiative forcing due to aerosols.

The scientific community is aware that the efficiency of models developed for policymakers and mitigation policies will depend on including more complex probabilistic approaches and would need new social-economic inputs involving policymakers, investors, and industry. Trajectories to explore possible changes in future energy production and use, greenhouse gas emissions, and temperature depend on which policies are enacted and when and where they can allow better baselines for the needed policy push to keep global temperature rise below 1.5 ºC.

The new generation of models in the lead by AR6 incorporates a consistent set of five Shared Socioeconomic Pathways (SSPs) and technological trajectories that the world could follow in this century (Riahi[55] et al., 2016). Each has a baseline in which no climate policies are enacted after 2010 - resulting in between 3 °C and 5 °C of warming above pre-industrial levels by 2100 (Table 2).

The scenarios assumed in the SSPs simulations, representing different challenges for adaptation and mitigation policies to face climate change, were as follows (IPCC[56], 2019):

- SSP1 includes a peak and decline in population (~7 billion in 2100), high income and reduced inequalities, effective land-use regulation, less resource intensive consumption, including food produced in low-GHG emission systems and lower food waste, free trade and environmentally friendly technologies and lifestyles. Relative to other pathways, SSP1 has low challenges to mitigation and low challenges to adaptation (i.e., high adaptive capacity).
- SSP2 includes medium population growth (~9 billion in 2100), medium income, technological progress, production and consumption patterns are a continuation of past trends, and only a gradual reduction in inequality occurs. Relative to other pathways, SSP2 has medium challenges to mitigation and medium challenges to adaptation (i.e., medium adaptive capacity).
- SSP3 includes high population growth (~13 billion in 2100), low income and continued inequalities, material-intensive consumption and production, barriers to trade, and slow

[55] Riahi, K., van Vuuren, D.O., Kriegler, E., Edmonds, Jae at al. (2016) - The Shared Socioeconomic Pathways and their energy, land use, and greenhouse gas emissions implications: An overview. *Global Environmental Change* 42: 153-168

[56] IPCC (2019) – Summary for Policymakers. In: *Climate Change and Land*: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.- O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)].

rates of technological change. Relative to other pathways, SSP3 has high challenges to mitigation and high challenges to adaptation (i.e., low adaptive capacity).

- SSP4 includes medium population growth (~9 billion in 2100), medium income, but significant inequality within and across regions. Relative to other pathways, SSP4 has low challenges to mitigation, but high challenges to adaptation (i.e., low adaptive capacity).

SSP5 includes a peak and decline in population (~7 billion in 2100), high income, reduced inequalities, and free trade. This pathway includes resource-intensive production, consumption and lifestyles. Relative to other pathways, SSP5 has high challenges to mitigation, but low challenges to adaptation (i.e., high adaptive capacity).

Table 2 – Temperature projections based on the RCPs

SSP Scenario	Range of global mean temperature increases to 2100 from pre-industrial baseline (ºC)
RCP1.9	~1 to ~1.5
RCP2.6	~1.5 to ~2
RCP3.4	~2 to ~2.5
RCP4.5	~2.5 to ~3
RCP8.5	~5

In addition, the SSPs can be linked to climate policies to generate different outcomes for the end of the century (analogous to RCPs), with a radiative forcing of 1.9, 2.6, 3.4, 4.5, 6.0, 7.0 or 8.5 Wm^{-2} in 2100 (Fig. 7).

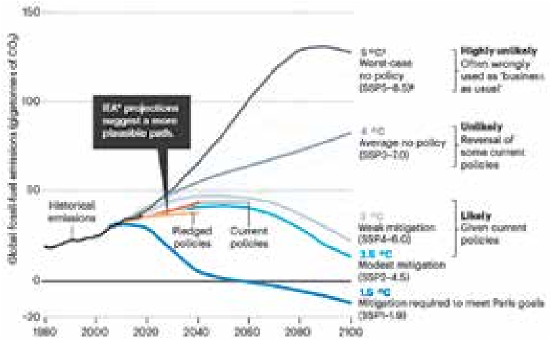


Fig. 7 - Different energy policy and investment choices (it includes countries' current policy pledges and targets as well as non-fossil fuel emissions from industry in 2018. (Data source: International Energy Agency, IEA). ± SSP5-8.5 replaces RCP8.5 (in: Hausfather & Peters, 2020)

5 - The Mediterranean region: Important issues

5.1 - Natural restrictions, human context

Within the high fixity of ways of life, the Mediterranean basin has known many ups and downs in its history, punctuating periods of prosperity and cultural irradiation with periods of stagnation and decay.

In the Mediterranean basin, distant pasts have seen significant climatic changes with temperatures that supposedly were, on average, 8 °C lower than today (20,000 years ago) or much higher by 1 to 3°C (20,000 to 6,000 years ago). Depending on the period, the landscapes, the fauna and flora, and the carving of the coasts (due to variations in the sea level of several tens of meters) were significantly different. These estimates allow concluding that actual anthropogenic activities cause climate changes not only comparable to natural ones but on a much faster timescale. If the current trends in emissions of greenhouse gases are not changed, global temperatures will probably rise faster over the 21st century than over any time during the last 10,000 years (IPCC, 1996).

These evolutions were spread over several hundred, even thousands of years. On the other hand, the current situation and that expected in the coming years are characterized by rapid rates of change. This factor makes the magnitude of the anticipated impacts more critical because the relatively quick changes do not allow ecosystems and societies' gradual acclimatization and adaptation. In addition, meteorological events on a scale never recorded before. Southern and Eastern Europe registered record-breaking temperatures in July 2023 as a searing heatwave set in. Parts of Italy saw highs of 48°C and increased temperature-related deaths. Greece, too, has seen highs of over 40°C, forcing the Acropolis in Athens to close during the hottest part of the day to protect visitors. Southeast of the capital, thousands have been forced to evacuate resort towns as wildfires raged. Spain's weather service said thermometers hit values of 45°C in south-eastern areas of the Iberian Peninsula, which are also under an alert for extreme heat. The current extreme heat was due mainly to a slow-moving anticyclone, a high-pressure system that dominated the upper atmosphere over southern Europe (ECMWF[57], 2023).

Since 1970, southwestern Europe (the Iberian Peninsula, southern France) has experienced a temperature increase of nearly 2 °C (IPCC 2007). This warming is also perceptible in northern Africa, even if it is more difficult to quantify due to a less complete observation network.

In nature, so praised, not everything favours the man. The culture of steep lands, always subject to violent floods, requires permanent vigilance to avoid transforming the soil into hard, sterile rock.

Irrigation that extends the cultivation period and makes it feasible in the most dry and semi-arid areas requires constant cleaning and conservation work to conserve ditches, channels and irrigation implements. The fertility of many of these regions is a fragile work of man and not a gift permanent of nature. History shows that to the harshness of nature, conflicts arise from the clash of different ways of life and the sudden opposition of the regions. That is why Orlando Ribeiro[58] (1988) says that "*In no other space on the globe do the relations of geography and history form, as in the Mediterranean, a thick and inseparable plot*".

The world, and in particular the Mediterranean basin, is faced with many challenges, such as human inequalities, large flows of distress migration, limited access to natural resources (water, land, and biodiversity) and their mismanagement. These multidimensional factors made Quezel[59] (1985) stating that the Mediterranean region is one of the most complex and heterogeneous areas of the world, under environmental and biogeographical points of view.

[57] ECMWF (2023) - European heatwave July 2023. European Center for Medium-Range Weather Forecasts., 2023

[58] Ribeiro, Orlando (1978) – *Portugal, o Mediterrâneo e o Atlântico. Esboço de relações geográficas*. Livraria Sá da Costa Editora, 7nd ed., 190 pp.

[59] Quezel, P. (1985) – Definition of the Mediterranean region and the origin of its flora. Gomez-Campo (edit), "*Plant conservation in the Mediterranean area*", Springer Dordrecht, 9-24.

Different forms of waste, affecting food availability, natural resources, and knowledge, are intrinsically linked to these challenges representing major obstacles to achieving sustainability.

In general, the Mediterranean Region climate is characterised by mild wet winters and by warm to hot dry summers that may occur on the West Side of the continents between about 30^{o} and 40^{o} latitude. Still, climate change is exacerbating existing environmental fragilities and degradation in the Mediterranean basin. While the region's climate is diverse and spatially variable, several areas are classified as arid, semi-arid or desert. The region is a transition zone between a temperate European climate with relatively abundant and constant water resources and the arid desert climates of Africa and the Middle East, whose water resources are very scant.

A combination of factors has placed severe constraints on the Mediterranean's water resources. These include climate change, anthropic pressures arising from growing water demand for domestic and industrial uses, the development of irrigated zones and tourism. More than half of the world's "water poor" population is concentrated around the Mediterranean basin, which holds only 3 percent of the world freshwater resources (UNEP/MAP[60], 2017). These constraints are also a major cause of Mediterranean forest degradation.

The Mediterranean Sea is an almost closed basin, connected to the Atlantic Ocean through the narrow and shallow Gibraltar strait and is surrounded by high mountain ridges on almost every side. Furthermore, strong albedo[61] differences exist in south-north directions (Bolle[62], 2003), with important consequences on air masses and atmospheric circulation at the regional scale. It is an important heat reservoir and a source of moisture for surrounding land areas, representing an important source of energy and moisture for cyclone development. Its complex land topography plays a crucial role in steering airflow, characterising the atmospheric circulation.

Because of its latitude, the Mediterranean is in a transitional zone where both mid-latitude and tropical variability competes against each other. Additionally, the Mediterranean climate is exposed to the South Asian Monsoon in summer and the Siberian high-pressure system in winter. The southern part of the region is mainly under the influence of the descending branch of the Hadley cell[*], while the northern part is more linked to the mid-latitude variability.

The Mediterranean Basin is also influenced by semi-permanent large-scale anticyclones (e.g., the Azores anticyclone in the west during summer and the cold Siberian anticyclone

in the northeast during winter), while mobile anticyclones also play an important role throughout the whole year. During the summer, the climate of the Mediterranean is further influenced by circulation patterns set up by the Asian summer monsoon and local orography

---

60 UNEP/MAP (2017) -Agenda item 4: Review of quality status report (QSR). Quality status report (QSR) cross-cutting and horizontal issues. Working document of the 6th Meeting of the Ecosystem Approach Coordination Group, Athens, 11 September 2017 UNEP(DEPI)/MED WG.444/11, Athens, United Nations Environment Programme / Mediterranean Action Plan. 15 pp.

61 *Surface albedo is the measure of the diffuse reflection of solar radiation out of the total solar radiation and measured in a scale of 0 (black body that absorbs all incident radiation) to 1, corresponding to a body that reflects all incident radiation.*

62 Bolle, H.J. (ed) (2003) – *Mediterranean Climate – Variability and Trends*. Springer Verlag, Berlin, 372 pp.

* The Hadley cell, also known as Hadley circulation, is a global-scale tropical atmospheric circulation that features air raising near the equator, flowing poleward near the tropopause at a height of 12-15 km above the Earth's surface, cooling and descending in the subtropics at around 25 degrees latitude, and then returning equatorward near the surface. It is a thermally direct circulation within the troposphere that emerges due to differences in insolation and heating between the tropics and the subtropics. The prevailing trade winds are a manifestation of the lower branches of the Hadley circulation.

(Simpson[63] et al. 2015). The large-scale wintertime circulation has exhibited a long-term trend toward increased sea level pressure and anticyclonic circulation over the Mediterranean. Aside from this long-term trend, the historical record has also shown sizable multi-decadal variability. This is illustrated for the sea-level pressure anomalies and has also been discussed widely in the contexts of trends in the North Atlantic Oscillation (NAO) and associated Mediterranean drying that occurred over the latter half of the 20th century in which internal variability is thought to play an important role (Kelley[64] et al. 2012).

These multiple influences make the Mediterranean to be considered a hotspot for climate change due to higher warming in both air and sea than the global average and by changes in water regimes in a region where water scarcity is already a reality. In fact, temperatures have increased by 1.5 ºC since the late 19th century, compared to the world average increase of 1.1 ºC since the industrial revolution (Woetzel[65] et al., 2020). The warming effect in the Mediterranean is now more intense than in most of the world with increasing risks associated with climate change (Cramer et al.[66], 2018). CO_2 induced acidification is further threatening its marine ecosystems.

The region is also vulnerable to the impacts of sea-level rise with dense human settlements, infrastructures and heritage sites close to the shore and often with limited adaptive capacity. The Mediterranean Sea identifies an area shared by three continents, distributed into four macro-areas: Western Europe, Eastern Europe, Middle East, North Africa (MENA), and each showing accentuated differences in demography, culture, and traditions, social, religions, economy, and particular constraints for agriculture intensification. Adding to the 21 countries directly facing the Mediterranean Sea, Portugal, North Macedonia, and Jordan are included in this area because of their geopolitical influence.

Besides a climate hotspot, the Mediterranean basin is also considered a biodiversity hotspot. The Mediterranean basin, extending over 2 million square kilometres, is the largest of the world's five Mediterranean Climate regions and the world's second-largest biodiversity hotspot (Myers[67] et al., 2000). The Mediterranean basin is rich in plant diversity, containing some 25 000 plant species, 60 percent of which are endemic (Myers et al., 2000; Thompson[68], 2005). The region also contains a great wealth of endemism in trees and shrubs (290 indigenous woody species and subspecies, 201 of which are endemic (Fady-Welterlen[69], 2005). Quite a number of these are flagship species, such as the Lebanese cedar, *Cedrus libani*), argan tree (*Argania spinosa*) and the date palm of Crete (*Phoenix theophrasti*). The Mediterranean basin is also home to more than 220

---

63 Simpson I.R., Seager R., Shaw T.A., Ting, M. 2015 - Mediterranean summer climate and the importance of middle East topography. *J. Clim*. 28, 1977–1996. [doi: 10.1175/jcli-d-14-00298.1]

64 Kelley C., Ting. M., Seager, R., Kushnir, Y. (2012) - The relative contributions of radiative forcing and internal climate variability to the late 20th century winter drying of the Mediterranean region. *Clim. Dyn.* 38: 2001–2015. [doi: 10.1007/s00382-011-1221-z]

65 Woetzel, Jonathan, Pinner, Dickon, Samandari, H., Engel, H., Krishnan, M., Vasmet, M., von der Leyen, Johanna (2020) – *A Mediterranean basin without a Mediterranean climate? Case Study*. McKinsey Global Institute 23 pp.

66 Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, Jean-Pierre, Iglesias, A., Lange, M.A., Lionnello, P., Llasat, M. C., Paz, S., Peñuelas, J., Snoussi, M., Toreti, A., Tsiplis, M. N. & Xoplaki, E. (2018) - Climate change and interconnected risks to sustainable development in the Mediterranean. *Nature Climate Change* 8: 972-980.

67 Myers, N., Mittermeier, R.A., Mittermeier, C.G., da Fonseca, G.A.B. & Kent, J. (2000) - Biodiversity hotspots for conservation priorities. *Nature*, 403(6772): 853–858.

68 Thompson, J.D. (2005) - *Plant evolution in the Mediterranean*. Oxford, UK, Oxford University Press. 304 pp.

69 Fady-Welterlen, B. (2005) - Is there really more biodiversity in Mediterranean forest ecosystems? *Taxon*, 54(4): 905-910.

species of terrestrial mammals, 25 of which are endemic (11 %) (Derneği[70], 2010). Mediterranean forest ecosystems are very much tied to human activity: the current level of endemism and biodiversity is the result of this interaction. The impact of the increased pressure on these ecosystems will, however, be diffuse. Notably, the loss of biodiversity in these areas will inevitably affect their future economic potential. Nowadays, protected areas cover only 9 million hectares, representing 4.3 % of the region's total surface area. The largest protected area lies in the north (UNEP-WCMC and IUCN[71], 2017). This number raises questions about the effectiveness of efforts to protect and conserve Mediterranean forests.

One of the main reasons explaining this abundance is due to the refuge function of the species during the glacial age: the post-glacial colonization of the whole of Europe has restarted from the Mediterranean basin, particularly from its main peninsulas. Medail[72] and Quezel (1997) have identified some sub-hotspots of plant endemism and richness: the Baetic-Rifan complex (Spain), the Maritime and Ligurian Alps (Italy, France), the Southern and Central Greece, Crete (Greece), the Tyrrhenian Islands (Italy, France), Anatolia (Turkey) and Cyprus. Subsequent studies in this regard (Médail[73] and Diadema, 2009) found an apparent spatial congruence between these regions and glacial refuge areas identified from phylogeographical surveys. Protected areas in the Mediterranean basin, whose creation started at the beginning of the the1900s, reach today's coverage of around 10.1 % of the territory. It has been shown that these protection systems are effective enough to protect current biodiversity (Noce[74] et al. 2016). Still, it is undoubtedly necessary to consider future climate change scenarios for reshaping them, for designing new ones and, in general, for appropriately updating all the environmental protection policies (Noce[75] et al., 2017).

MENA regions have long been challenged to provide sustainable livelihoods for their populations in the fragile ecosystems of semi-arid and arid areas. The region faces the challenging issues of absolute water scarcity, drought, land degradation, and desertification. In addition, the region has to deal with other problems, including a significant increase in population, poverty, a geopolitically fragile environment, gender imbalance, weak investment in agricultural research for development, and constraints in human resources and institutional capacities. Despite that, they are deeply interconnected through the sea concerning migration, trade, and energy fluxes.

The population of these 24 countries has more than doubled since 1960 to more than 520 million people, although growth trends in the four macro-areas are, however, significantly distinct as is their level of development: 33 % in South Europe, ≈ 250 % in the Middle East and North Africa. From 2008-2018, the Mediterranean population increased by 11 %, compared with rates of about 2 % in Western Europe, 18% in the Middle East and 20 % in North Africa.

---

[70] Derneği, D. (2010) - *Profil d'écosystème. Hotspot de la biodiversité du bassin méditerranéen.* Arlington, USA, Critical Ecosystem Partnership Fund. 258 pp.

[71] IUCN. (2017) - The IUCN Red List of threatened species. Version 2017-1. In: IUCN Global Species Programme Red List Unit [online]. Cambridge, UK, International Union for Conservation of Nature. Accessed: June 2021. [http://www.iucnredlist.org].

[72] Médail, F.and Quezel,P. (1997) - Hot-Spots Analysis for Conservation of Plant Biodiversity in the Mediterranean Basin. *Annals of the Missouri Botanical Garden*, 84(1):112.

[73] Médail, F. and Diadema, K. - (2009) - Glacial refugia influence plant diversity patterns in the Mediterranean Basin. *Journal of Biogeography*, 36(7): 1333–1345.

[74] Noce, S., Collalti, A., Valentini, R. and Santini, M. (2016) - Hotspot maps of forest presence in the Mediterranean basin. *Forest-Biogeosciences and Forestry*, 9(5): 766–774.

[75] Noce, S., Collalti, A., and Santini M. (2017) - Likelihood of changes in forest species suitability, distribution, and diversity under future climate: The case of Southern Europe. *Ecology and Evolution*, 7(22): 9358–9375

As measured by the Human Development Index (HDI), disparities in human development are also flagrant among Mediterranean countries and aggravated by conflicts. They reflect the geographic and economic divide between North Mediterranean Countries (NMCs) and Southern Mediterranean Countries (SEMCs), apart from Israel. In European Union (EU) countries, higher income, coupled with social security systems and investment in education, has increased life expectancy at birth and years of schooling. Despite demographic growth, geopolitical difficulties, conflicts, and human development differences, it has experienced an upward trend throughout the last decade, significantly increasing in almost all countries.

Most SEMCs have conducted policies to provide widespread access to education in primary and secondary schools. The expected number of years of schooling for new generations is not far from the European standards, except for tertiary education, to which access remains unequal. Girls' education has also improved with an increased gender parity index for enrolment in primary and secondary schools in most Mediterranean countries. However, a challenge still lies in the quality of the education provided and the abandonment of schooling. The average length of schooling in Mediterranean countries is nine years, but the range is considerable (from 4.4 years in Morocco to 12.9 years in Israel) (UNDP[76], 2016). Education rates vary considerably between rural and urban areas, but there is little evidence on which to provide accurate data.

The World Economic Forum (WEF) has produced a Human Capital Index (HDI) that measures the knowledge and skills people possess enabling them to create value in the global economic system, which most African Mediterranean countries are lagging.

Although countries along the Mediterranean Sea share a common heritage, exposure to climate and environmental risks and impacts, urbanization, coastal erosion, and increasing tourism pressure, the contrast among Mediterranean countries is also significant: throughout the past decade, gaps have persisted between NMCs and SEMCs in terms of demographic dynamics, human development, access to natural resources and environmental protection.

These differences lead to significant inequalities in resilience and adaptive capacity to deal with current and projected environmental and climate changes. Recent estimates of the cost of environmental degradation attest to the magnitude of these effects, exacerbated by conflict situations.

Diverse are also the levels of poverty and development among the macro-areas identified, reflecting the geographic and economic divide between MNCs and SEMCs (Table 3 and 4).

The population distribution in the area shows a growing depopulation of rural areas - employment in the agriculture sector decreased 40 % (WB[77] data, 2020) and a growing urbanized population reaching around 70 %.Although it is commonly admitted that the world remains an interconnected environment where the capital, goods, services, and ideas are highly mobile, and innovations in information technology facilitate their circulation, Mediterranean countries are sociologically and economically very diverse, generating well-marked states of tension between and within the various regions with differentiated impacts about agriculture and socio-economic

---

[76] UNDP – (2016) - Human development report 2016. Human development for everyone. New York, USA, United Nations Development Programme. 271 pp.

[77] World Bank (2020) – World Bank open data. WB, Washington (DC). Available at: https://data.worldbank.org

development and adaptive responses to food systems and food security and climate mitigation interventions (UNEP[78], 2020).

Table 3 – Proportion of people living below 50% of median income.

Countries and regions	Head count ratio (%)	People living below 50% of median income (%)	Human Development Index (HDI) 2021 *
France	0,30	10,10	0.903
Greece	2,42	14,90	0.887
Italy	1,78	16,00	0.895
Malta	0,16	9,40	0.918
Portugal	0.89	11,00	0.866
Spain	1,32	16,10	0.905
Albania	4,35	12,00	0.796
Croatia	1,14	13,20	0.858
Cyprus	0,08	8,50	0.896
Montenegro	0,08	20,50	0.832
North Macedonia	8,10	17,70	0.768
Bosnia & Herzegovina	0,23	--	0.780
Slovenia	0,22	6,40	0.918
Israel	0,62	21,20	0.919
Jordan	9,19	--	0.720
Lebanon	0,06	0,00	0.706
Palestine	9,40	17,20	0.715
Syrian Arab Rep.	--	0,00	0.577
Turkey	0,33	15,60	0.838
Algeria	1,97	--	0.745
Egypt Arab Rep.	9,46	5,20	0.731
Libya	--	--	0.718
Morocco	4,53	--	0.683
Tunisia	2,15	10,40	0.731

* Human Development Report 2021-22

[78] UNEP (United Nations Environment Programme), (2020) – State of the Environment and Development in the Mediterranean. 2020 Report. UN, NY 341 pp.

Table 4 – Level of development and population in Mediterranean countries

Countries and regions		Income Group	Population	SDG Index Score (*)	Global rank
France	E.west	HIC	65,273,512	81.1	4
Greece	E.west	HIC	10,423,056	74.3	43
Italy	E.west	HIC	60,461,828	77.0	30
Malta	E.west	HIC	441,539	76.0	32
Portugal	E.west	HIC	10,196,707	77.6	25
Spain	E.west	HIC	46,754,783	78.1	22
Europe West	E.west	--	193,551,425	78.5	18
Albania	E. east	UMIC	2,877,800	70.8	68
Bosnia & Herzegovina	E. east	UMIC	3,280,815	73.5	50
Croatia	E. east	HIC	4,105,268	78.4	19
Cyprus	E. east	HIC	1,207,361	75.2	34
Montenegro	E. east	UMIC	628,062	70.2	72
North Macedonia	E. east	UMIC	2,083,380	71.4	62
Slovenia	E. east	HIC	2,978,932	79.8	12
Europe East	E. east	--	16,261,618	74.8	38
Southern Europe		--	209,813,043	78.2	20
Israel	ME	HIC	8,655,541	74.6	40
Jordan	ME	UMIC	10,203,140	68.1	89
Lebanon	ME	UMIC	6,825,442	66.7	95
Palestine	ME	-	-	-	-
Syria	ME	LIC	-	59.3	126
Turkey	ME	UMIC	84,339,067	70.3	70
Middle East	ME	-	116,848,632	70.2	72
Algeria	NA	UMIC	43,851,043	72.3	56
Egypt	NA	LMIC	102,334,403	68.8	83
Libya	NA	-	-	-	-
Morocco	NA	LMIC	36,910,558	71.3	64
Tunisia	NA	LMIC	11,818,618	71.4	63
North Africa	NA	-	194,914,622	70.2	72
Mediterranean Area	Med	-	521,576,297	73.5	50

(*) SDG index score tracks country performance towards the SDG. All 17 goals are weighted equally in the index and the score signifies a country's position between the worst (0) and the best or target (100) outcomes.

LIC (Low Income countries, GNI < USA $1,135); LMIC (Low middle-income countries, GNI between 1,136 – 4,465); UMIC (Upper middle-ncome countries, GNI between 4,466-13,845); HIC (Higher income-countries, GNI > 13,846) (Reference values, 2022, WB)

The Mediterranean region is also characterized by very limited arable land resources, 95 % of which are already farmed (UfM[79], 2016). With almost no room left for the expansion of cultivated areas, the future of Mediterranean agriculture and its contribution to food security relies on the preservation of fragile lands threatened by climate change, unsustainable exploitation, and population growth (MedECC[80], 2019). Since the 1970-1990 period, there has been a territorial specialization in land distribution, mainly in the European Mediterranean area. On the one hand, there are highly productive intense farming and forestry areas and, on the other, increasingly marginalized small-scale farm mosaics, extensive land-use systems, or even abandoned land.

If the countries of the northern shore can theoretically offer new agricultural opportunities, but to the detriment of areas that are often very important on an eco-systemic level, this is not the case in the Middle East and North Africa (MENA) region, characterised by the scarcity of their arable land reserves suitable for agriculture production. Due to the prevailing aridity, inherently poor and human-degraded soils – especially in the mountainous areas – and limited rainfall and water supplies make agricultural practice very difficult. The scarcity of arable land and available water are among the main reasons why the MENA region strongly relies on food imports to feed its people.

Furthermore, competition for land driven by strong economic interests and increased population leads to increasing pressure on natural resources. In regions such as the MENA region, where climatic conditions are particularly unfavourable, land degradation and desertification threaten people's livelihoods and food security.

There is great confidence that soil degradation negatively affects people's livelihoods, and that this phenomenon occurs over a significant area, more than a quarter of the Earth's ice-free surface. Most of the 1.3 to 3.2 billion people affected by this degradation in developing countries live in poverty (Olson[81]et al., 2022). Direct human interventions in agricultural activities, through inadequate soil use and management, are the dominant factors in soil degradation. Soil degradation affects humans in multiple ways, interacting with social, political, cultural and economic aspects, including markets, technology, inequality and demographic changes. However, the impacts of land degradation extend beyond the Earth's surface, affecting marine and freshwater systems, people and ecosystems far from local degraded sites.

In the Northern Mediterranean Countries, Portugal is a unique case study with a significant deficit in the agri-food trade balance (GPP, 2017) and was severely affected by the sovereign debt crisis that impacted both agricultural production and food consumption. It is also one of the European countries that incurred higher costs due to extreme events: 0.14 % of GDP (EEA[82], 2017).

---

[79] Union for the Mediterranean (UfM), (2016) - Key players' perspective on climate change in the Mediterranean. Barcelona. [online at: [https://ufmsecretariat.org/wpcontent/ uploads/2016/11/UfM_SectoralReport_2016_EN_web1.pdf]

[80] Mediterranean Experts on Climate and Environmental Change (MedECC). Risks Associated to Climate and Environmental Changes in the Mediterranean Region: A Preliminary Assessment by the MedECC Network Science-Policy Interface. MedECC - (2019). [online at: http://www.medecc.org/wpcontent/uploads/2018/12/MedECC-Booklet_EN_WEB.pdf]

[81] Olsson, L., H. Barbosa, S. Bhadwal, A. Cowie, K. Delusca, D. Flores-Renteria, K. Hermans, E. Jobbagy, W. Kurz, D. Li, D.J. Sonwa, L. Stringer (2022) - Land Degradation: 345-436. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems. [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D. C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley, (eds.)]. Cambridge University Press, 910 pp.

[82] European Environment Agency EEA (2017) - 2016 assessment of the progress made by Member States in 2014 towards the national energy efficiency targets for 2020 and towards the implementation of the Energy Efficiency Directive

The foreseeable impact of climate change impending over Portugal will be treated in Part II of this review.

These strong contingencies cement the belief that the future of Mediterranean agriculture and its contribution to food security, relies on preserving its fragile lands threatened by climate change, unsustainable exploitation, and population growth (Zdruli[83] et al. 2016).

People in the water-poor Mediterranean region have always had to cope with scarcity, developing adaptation strategies to meet their most essential needs. Although Mediterranean countries are engaging in a multitude of commitments and efforts to mitigate and adapt to climate change, at the international, regional, national, and local levels, forecasts reveal that despite the adaptation capacities in place, the number of water-poor people in the region will increase from 180 million in 2013 to more than 250 million within the next 20 years (MedECC[84], 2019). In the meantime, unsustainable water use, and wastage contribute to the depletion of the resources when water needs, driven by economic and demographic growth, are ever-increasing.

5.2 - Climate Changes in the Mediterranean Basin

Although the Mediterranean Basin is known to be a climate hot spot, it has benefited from climatic conditions that have allowed the development of rich landscapes with high biodiversity and sophisticated land-use systems, providing numerous services to people, including the recognition of the so-called Mediterranean diet thanks to the richly diverse range food products of its agriculture. A key characteristic of the Mediterranean climate is hot and dry summers, creating water-stressed conditions meaning that vegetation can only develop via substantial replenishment of groundwater resources from heavy rainfall in winter in the coastal regions and the melting of snow and ice in the high mountains during summer. These unusual conditions occur in just a few areas of the world.

The Mediterranean Basin has been affected by recent climate change at rates exceeding global averages, in particular by more rapid warming during all seasons, in the air and sea. There is an unequivocal trend towards drier conditions, with the noticeable specificity that most climate models are in stronger agreement about expected rainfall changes in the Mediterranean than in anywhere else. Economic activities (agriculture, fisheries, tourism, etc.) and supporting infrastructure (cities, ports, agriculture in low-lying river deltas, etc.) are tightly tuned to recent climatic and environmental conditions, particularly the precise current level of the sea surface, making Mediterranean countries highly vulnerable to changes in these conditions. All these factors together make the Mediterranean Basin a climate change hotspot where large populations, mostly those living in the MENA region, are foreseeably more vulnerable to climate change impacts already now and in the very near future.

2012/27/EU as required by Article 24 (3) of the Energy Efficiency Directive 2012/27/EU. Report from the Commission to the European Parliament and The Council. [https://ec.europa.eu/commission/sites/beta-political/files/report-energy-efficiency-progress_en.pdf]

[83] Zedruli, P., Ziadat, F., Nerili, E., D'Agostino, Daniela, Lahamer, Bunning, Sally, (2016) – Sustainable Development of Land Resources. 91-111. In: Zero Waste in the Mediterranean. Natural Resources, Food and Knowledge. Mediterra. International Centre for Advanced Mediterranean Agronomic Studies, FAO., 416 pp.

[84] MedECC (2020) - Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report [Cramer, W., Guiot, J., Marini, K. (eds.)] Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632pp. [https://www.medecc.org/first-mediterranean-assessment-report.mar1]

Recent climate change in the Mediterranean exceeds global trends for several variables. While global mean surface temperature is now about 1.1 °C (±0.10 °C likely range, IPCC[85], 2019a) above pre-industrial values, the Mediterranean region approaches 1.54 °C (Cramer[86] et al., 2018) (Fig. 8). The period from February 2023 to January 2024 reached 1.52C of warming, according to the EU's Copernicus Climate Change Service.

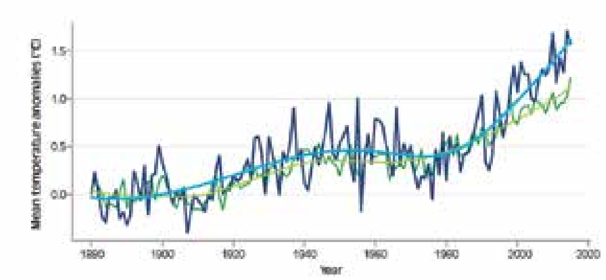


Fig. 8 – Historic mean air temperature trends, globally in the Mediterranean basin
Blue line in the Mediterranean; green in the planet (annually and smoothing)
(Source: UNEP[87], 2020)

The lands in the Mediterranean basin are known to be one of the fastest warming parts of the world in boreal summer: the ERA5 data for this Southern Europe region has a linear trend for July of 0.54°C/decade from 1979 to 2023, which is three times larger than the trend for global-average July temperatures. July 2023 is the warmest month in the ERA5 data record for the region, with an average temperature of 25.6°C. The next warmest month is July 2015, followed by July 2022. In both cases the average temperature for the month rounds to 25.3°C. Temperature trends are set forth in Fig. 9.

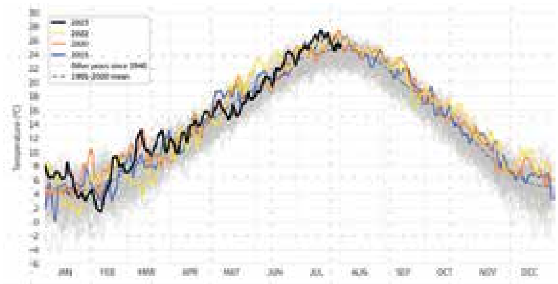


Fig. 9 – Daily surface air temperature averaged over the Southern European (25^{o}W – 40^{o}E; 34^{o} - 45^{o}N) region from 1 January 1940 to 23 July 2023
Data source: Climate Change Service, Climate Copernicus EU.

[85] IPCC (2019a) – Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and gereenhouse gas fluxes in terrestrial ecosystems: Geneva, Switzerland. In press

[86] Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J-P., Iglesias, A., Lange, M.A., Lionello, P., Llasat, M.C., Paz, S., Peñuelas, J., Snoussi, M., Toreti, A., Tsimplis, M.N. & Xoplaki, E. (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. *Nature Climate Change, 8*: 972-980.

[87] UNEP, 2020. SOED (State of Environment and Development in the Mediterranean) Report, 342 pg.

Since the mid-20th century, the major causes of the air temperature increase in the Mediterranean region are anthropogenic factors (Adloff[88] et al., 2015). This also includes the observed increases in hot extremes and decreases in cold extremes (Bindoff[89] et al., 2013; Schleussner[90] et al., 2017). The length of meteorological dry spells is expected to increase significantly. In the absence of compliance with the decarbonization targets, temperatures are projected to increase by an additional 1.5 ºC by 2050 (Cramer et al., 2018). Consequently, rising temperatures are expected to raise hydrological variability, increasing the risk of drought, water stress, increased wildfires, and floods.

Vulnerability in the Mediterranean basin to climate extremes are highlighted by foreseeable water shortages and poor harvests during the droughts as happened in the early 1990s (Karas[91], 2006). There is a great confidence that the Mediterranean, and more particularly its southern and eastern shores, will be more affected by climate change than most other regions of the world during the 21st century. This is related to the fact that regional climate change is subject to complex interactions between multiple external forces and internal variability. The latter, at different time scales, can modify the amplitude of the temperature response, and the amplitude of signal of the precipitation response to anthropogenic forcing.

Factors such as: i) the effects of the rise in temperatures, ii) the existing negative trends of annual precipitation totals in the majority of Mediterranean regions during the period 1901-2009, with one exception of southern Italy and western Iberian peninsula, not statistically significant at 95% CL, (Philandras[92] et al., 2011), iii) the increase in the number and iv) the intensity of extreme events and the possible rise in the sea level, overlap and amplify the already existing pressures of anthropogenic origin on the natural environment.

A thorough discussion of these trends is an ongoing process that involves many scientists and institutions that address this discussion and develop increasingly comprehensive models to avoid opportunistic exploits by political, industrial, and commercial interests that can minimize the severity of the threat of climate change.

The above general characterization of global climate issues applied to the Mediterranean basin is mostly based on the evaluation of the contribution of GHG to energy equilibrium of the atmosphere-surface system and the regional and local anthropogenic spatial-temporal evolutions. The understanding of regional carbon cycling in the Mediterranean basin is an issue with high degrees of complexity. For example, assumptions like equality between net ocean carbon uptake of the anthropogenic perturbation and the net air-sea input plus runoff minus sedimentation are assumed in computation modelling.

---

[88] Adloff, F., Somot, S., Sevault, F., Jordà, G., Aznar, R. et *al*. 2015 Mediterranean Sea response to climate change in an ensemble of twenty first century scenarios. *Clim. Dyn*. 45: 2775 - 2802. [doi: 10.1007/s00382-015-2507-3]

[89] Bindoff, N.L., Stott, P.A., Achuta Rao, K.M., Allen, M.R., Gillet, N., Gutzler, D. Hansingo, K., et al. (2013) - *Detection and attribution of climate change: From global to regional*, 867-952. In: T.F. Stocker, D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex, and P.M. Midgley, Eds., Cambridge University Press.

[90] Schleussner C.F., Lissner, T.K., Fischer, E.M., Wohland, J., Perrette, M. et al. (2016) - Differential climate impacts for policy-relevant limits to global warming: The case of 1.5 °C and 2 °C. *Earth Syst. Dyn*. 7: 327 - 351. [doi: 10.5194/esd-7-327-2016]

[91] Karas, J. (2006) – Climate Change and the Mediterranean Region Report. Greenpeace. 34 pp. [in: http://www.citeseerx.ist.psu.edu/viewdoc/download?doi=101.1626.9955&rep=rep1&typy=pdf] (accessed on 10th May 2021)

[92] Philandras, C. M., Nastos, P.T., Kapsomenakis, J., Douvis, K.C., Tselioudis, G., and Zerefos, C. S. (2011) -Long term precipitation trends and variability within the Mediterranean region. Nat. Hazards Earth Syst. Sci. 11: 3235-3250.

Numerical regional circulation models to simulate the climate forecasts are being developed for the Mediterranean area with resolutions from 10 km x 10 km to 50 km x 50 km. The quality of such models depends on identifying systematic errors by testing the model's sensitivity to several feedback for years or decades. Based on the numerical solving of sets of finite differential equations, these models are implemented in regular node grids, with simulations for each node and time steps. Numeric resolution methods may not be resolute enough to depict many geographic features related to land-use changes, uneven spatial impact of aerosols, or variations in local microclimates, which can be representative of larger geographical scales.

Suitable parameterizations of heat, moisture, and momentum budgets on the Earth's surface are also essential to guarantee an accurate representation of proper climates by numerical modelling. Also, the climate change effects of varying concentrations of greenhouse gases, under progressive or transient response experiments, for example, by 1% per year or by sudden increases, can be assessed in real-time by changing the inputs to GCMs. Any model that predicts future climate can be checked "backwards" using paleoclimate or hindcasting records (Grounderbeek[93], *et al*., 2008).

Work on modelling developed since 1996 had made it possible to analyse how daily rainfall and the occurrence of temperature extremes had changed over a Mediterranean transect from the Iberian Peninsula to Greece during the second half of the 20th century (i.e. the period when a reanalysis of data by US National Centres for Environmental Prediction (NCEP) became available). The Mediterranean basin climate is also the result of climate interactions with other parts of the world through the atmosphere general circulation. It is directly linked to the Atlantic Ocean through its 14 km of Gibraltar straight so that its full-body water is entirely renewed approximately every 100 years.

More and more observation datasets have become available at regional scales, either from satellite or in-situ observations or from reconstructions and reanalyses. This new generation of observation-based products is: (1) long and homogeneous enough to allow trend studies (ESA-CCI) (Ribes[94] et al., 2019); (2) of sufficiently high spatial resolution to capture complex topography and land-sea mask (SAFRAN, EURO-4M), thereby allowing regional to local studies; and (3) of sufficiently high temporal resolution (daily or hourly, COMEPHORE) (Fumière[95] et al., 2019), to allow the study of regionally relevant extreme events. Finding the best fit-for-purpose observation dataset is becoming a new challenge, given many available products, often characterized by substantial differences. Results of past trend studies and model evaluations are sensitive to the choice of the reference dataset (Fumière et al., 2019). Long-term, accessible, gridded, well-calibrated, and homogeneous data in time and space in situ are still lacking, especially for the ocean or the high-frequency variables over land. In addition, regional model-based reanalyses are still rare.

Overall, the outputs from distinct downscaled models allow a common conclusion about an increase in air temperature during at least the first quarter of this century and the intensity of extreme weather and climate events. Despite significant uncertainties surrounding predictions of

---

[93] Grunderbeeck, and Tourre, Y. (2008) – Mediterranean Basin: Climate Change and Impacts During the 21st Century. Part I, Chapter 1, pp 1.1-1.64. In: *Climate Change and Energy in the Mediterranean. Plan Blue*, Regional Activity Center, Sophia Antipolis. [https://www.eib.org/attachments/ climate_change_energy_mediterranean_en.pdf]

[94] Ribes A, Thao S, Vautard R, Dubuisson B, Somot S et al. (2019) - Observed increase in extreme daily rainfall in the French Mediterranean. *Clim. Dyn*. 52:1095-1114. [https://link.springer.com/article/10.1007/s00382-018-4179-2].

[95] Fumière Q, Déqué M, Nuissier O, Somot S, Alias A et al. (2019) - Extreme rainfall in Mediterranean France during the fall: added value of the CNRM-AROME Convection-Permitting Regional Climate Model. *Clim. Dyn*., 1–15.

regional climate changes, there is a consensus on the projected increases in drought, floods, heatwaves and thermal stresses and their negative effects. Extreme events such as heatwaves, droughts, or floods are likely to be more frequent and violent in the Mediterranean basin.

5.2.1 - Changes in temperature

Climate reconstructions, ground-based observations, and remote-sensing datasets all corroborate a scenario of transition to warmer conditions during the last century, and that warming has accelerated during the last decades in the 21^{st} century. There is now strong evidence that the Mediterranean region has warmed unequivocally, as it is now evident from observations of increases in global average land (Fig. 10), air and sea temperatures, widespread melting of snow and rising global mean sea level.

Basin-wide, annual mean temperatures are now 1.5°C above late 19th century levels. Particularly after the 1980s, regional warming has accelerated and increased higher than the global average (Cramer[96] et al., 2018; Lionello[97] and Scarascia, 2018; Zittis[98] et al., 2019).

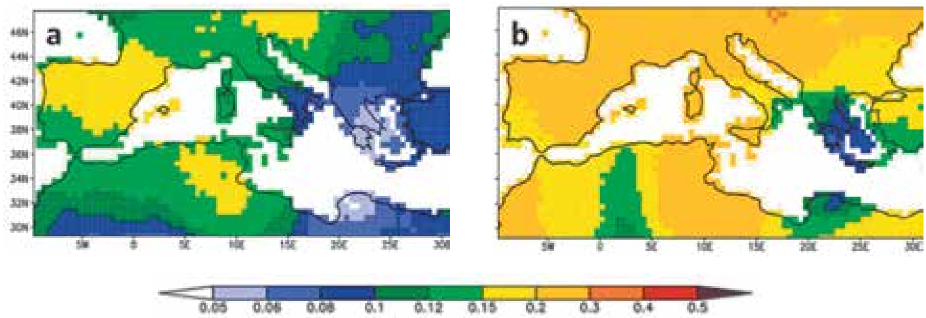


Fig. 10 - Observed changes in temperature over land in the Med. Basin in ºC. a) average for the period 1950-2018; b) for 1980-2018
Data source: MeDECC[99] (MAR 1), 2020

These studies present a strong consensus that the recent observed warming is robust throughout the region analysis. However, the magnitude and level of significance of the observed temperature trends in the Mediterranean vary depending on: (a) the region, country, or weather station under consideration; (b) the type of data set investigated, and (c) on the season and period of analysis. So, studies show that during the 20th century, air temperature in the Mediterranean

---

[96] Cramer W., Guiot J., Fader M., Garrabou J., Gattuso J-P et al. (2018) - Climate change and interconnected risks to sustainable development in the Mediterranean. *Nat. Clim. Chang.* 8, 972–980. [doi: 10.1038/s41558-018-0299-2]

[97] Lionello P., Scarascia L. (2018) - The relation between climate change in the Mediterranean region and global warming. Reg. Environ. Chang. 18: 1481–1493. [doi: 10.1007/s10113-018-1290-1]

[98] Zittis G., Hadjinicolaou P., Klangidou M., Proestos Y., Lelieveld J. (2019) - A multi-model, multi-scenario, and multi-domain analysis of regional climate projections for the Mediterranean. *Reg. Environ. Chang.* 19: 2621–2635. [doi: 10.1007/s10113-019-01565-w]

[99] MeDECC (2020) - Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report [Cramer, W., Guiot, J., Marini, K. (eds.)] Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632pp.

region rose in the range of 1.5 to 4°C, varying with the sub-regions. In the Iberian Peninsula, air temperatures rose in the same period by almost 2 ºC, with a clear increase since the seventies.

During the fall, Southern France, Spain, and northwest Africa were particularly sensitive to climate change. In these regions the temperature increases from during 1978 to 2003 about 0.5 ºC and over the 20th century about 0.75 ºC (Hansen[100] and DeFries, 2004). For three years, Northern Hemisphere's annual mean temperature during the 1990s were warmer than any other year since AD (Mann[101] et al., 1998).

Rising concentrations of greenhouse gases alone could cause warming over the Mediterranean region, similar in magnitude to the global increase. The same effects could be caused by internal variability factors, such as volcanic emissions or "el nino" sea currents. Results from four equilibrium experiments indicated that temperatures over the region could rise by about 3.5 °C between now and the latter half of the 21st century in response to a doubling of carbon dioxide or equivalent (Wigley[102]and Raper, 1992). Estimates from three transient model runs indicated that about half of this rise, between 1.4 and 2.6°C, could occur by the 2020s (Rosenzweig[103] and Tubiello, 1997).

Parallel evidence from numerical transient modelling from Kattenberg[104] et al., 1996, for the South Mediterranean basin pointed to temperature increases of 1°C to 4.5°C (with a mid-point of about 2.5°C) by the latter half of the 21st century. Even if emissions of greenhouse gases were stabilized by then, temperatures would continue to climb for several decades due to time lags in the response of the oceans (Karas, 2006). Hegerl[105] and Cubasch (1996), estimated by model results that by 2100, temperatures could rise by up to 2.5 to 3 °C across the Mediterranean Sea, 3 to 4 °C across coastal areas and 4 to 4.5 °C across most inland areas, with increases of up to 5.5 °C across Morocco. The general pattern of change suggested by these results is physically reasonable as warming on seas is likely to lag that over land areas.

Over the last decades, according to different type of observations, significant positive trends in increases of air temperature, of the order of 0.1-0.5°C per decade, have been identified for several countries of the Mediterranean (Feidas[106] et al., 2004; El Tanarhte[107] et al., 2012; Lionello

---

[100] Hansen, M.C., DeFries, R.S. (2004) – Detecting Long-term Global Forest Change Using Continuous Fields of Tree-Cover Maps from 8 km Advanced Very High-Resolution Radiometer (AVHRR) Data for the Years 1982-99, *Ecosystems* 7: 695-716.

[101] Mann, M.E., Bradley, R.S., & Hughes, M.K. (1998) – Global-scale temperature patterns and climate forcing over the past six centuries. *Nature*, 392: 779-787.

[102] Wigley, T.M.L. and Raper, S.C.B. (1992) – Implications for climate and see level of revised IPPC emissions. *Nature*: 357: 293-300.

[103] Rosenzweig, C. and Tubiello, F.N. (1997) - Impacts of global climate change on Mediterranean agriculture: Current methodologies and future directions: An introductory essay. *Mitig. Adapt. Strategies Glob. Change*, 1: 219-232 [doi:10.1007/BF00517804]

[104] Kattenberg, A. et al. (1996), Climate Change: The Science of Climate Change. In: Houghton, J. T. et al. (eds.), *Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge, U.K., pp. 285-357.

[105] Hegerl, G. C. & Cubasch, U. (1996) – Green gas induced climate change. *Environmental Science and Pollution Research*, 3: 99-102

[106] Feidas, H., Makrogiannis, T., Bora-Senta, E. (2004) - Trend analysis of air temperature time series in Greece and their relationship with circulation using surface and satellite data: 1955?2001. *Theor. Appl. Climatol.* 79: 185–208. [doi: 10.1007/s00704-004-0064-5]

[107] Tanarhte, M., Hadjinicolaou, P., Lelieveld, J. (2012) - Intercomparison of temperature and precipitation data sets based on observations in the Mediterranean and the Middle East. *JGR Atmos.* 117, n/a-n/a. [doi: 10.1029/2011jd017293]

and Scarascia, 2018; Bilbao[108] et al., 2019). In addition, there is some evidence that the diurnal temperature range has also changed for parts of the basin (Bilbao et al., 2019; Sun[109] et al., 2019).

Evidence from observations of the climate system showed that, over land, warming would likely be in the ranges of 0.9 to 1.5 °C or 3.7 to 5.6 °C during the 21st century for low (RCP2.6) or high greenhouse gas emissions (RCP8.5), respectively (Figs. 11 and 12).

Future regional average warming will exceed (high confidence) the global mean value by 20% on an annual basis and 50% in summer (MeDEC, 2020).

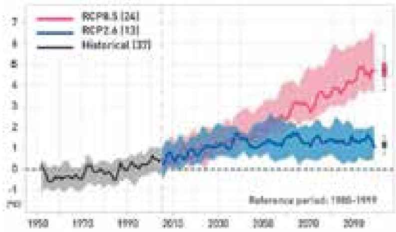


Fig. 11 – Projected warming in the Mediterranean Basin over land (reference period (1980-99) Data source: MeDECC[110] (MAR 1), 2020

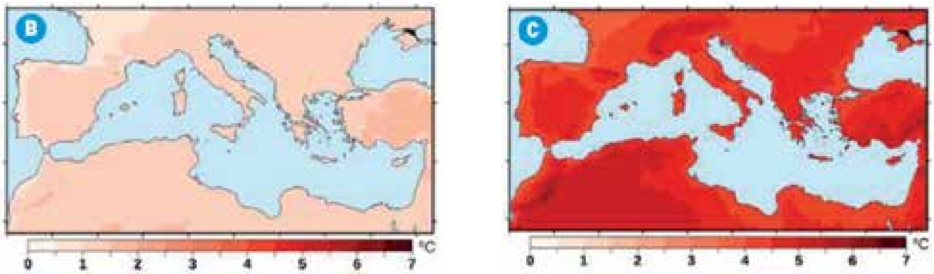


Fig. 12 - Projected warning anomalies in the Mediterranean Basin over land to the end of the 21st century (2080 -2099); B simulations for pathways RCP2.6; C idem for RCP8.5
Source: First Mediterranean Assessment Report[111], 2020

In the future, warm temperature extremes will increase, and heat waves will intensify in duration and peak temperatures. For 2 ºC of global warming above the pre-industrial value, maximum daytime temperatures in the Mediterranean will likely increase by 3.3 °C. Under a 4 °C global warming, the projections point that nearly all nights will be tropical (night-time temperature for at least five days above a location-depending threshold). There will be almost no cold days (below a location, depending on the threshold).

---

108 Bilbao, J., Román, R., de Miguel, A. (2019) - Temporal and Spatial Variability in Surface Air Temperature and Diurnal Temperature Range in Spain over the Period 1950–2011. *Climate* 7, 16. [doi: 10.3390/cli7010016]

109 Sun, X., Ren, G., You, Q., Ren, Y, Xu W. et al. (2019) - Global diurnal temperature range (DTR) changes since 1901. *Clim. Dyn.* 52, 3343–3356. [doi: 10.1007/s00382-018-4329-6]

110 MeDECC (2020) - Climate and Environmental Change in the Mediterranean Basin – Current Situation and Risks for the Future. First Mediterranean Assessment Report [Cramer, W., Guiot, J., Marini, K. (eds.)] Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632pp.ente

111 First Mediterranean Assessment Report (MAR1) (2020) – Climate and Environment Change in the Mediterranean Basin. Current situation and risks for the future. Ed. by Cramer, W., Guiot, J. and Marini, K. MedECC (Mediterranean Experts on Climate and Environmental Change. 628 pp.

Globally, by circa 2040, given the present global trend of 0.02±0.01°C per year, the temperature will likely surpass a 1.5 °C warming threshold. The corresponding trend in the Mediterranean region is about 0.03 °C per year, implying that when the world passes the 1.5 °C level identified in the Paris Agreement, the region will already be warmed by +2.2 °C.

Modelling projections for differences in areas within Europe, with the number of days per year with daily maximum temperatures higher than 30 ºC between now and the 2080s, point to a significant increase of these areas within the range of 100 to 200 daysyear^{-1} (Fig. 13).

As shown, this warming effect is particularly pronounced in the Mediterranean basin in general. The Iberian Peninsula is remarkedly affected, with a significant area presumably included in the 100-to-200-day class. It is legitimate to believe that its agricultural and forestry sector will be the most affected by climate change in Mediterranean Europe.

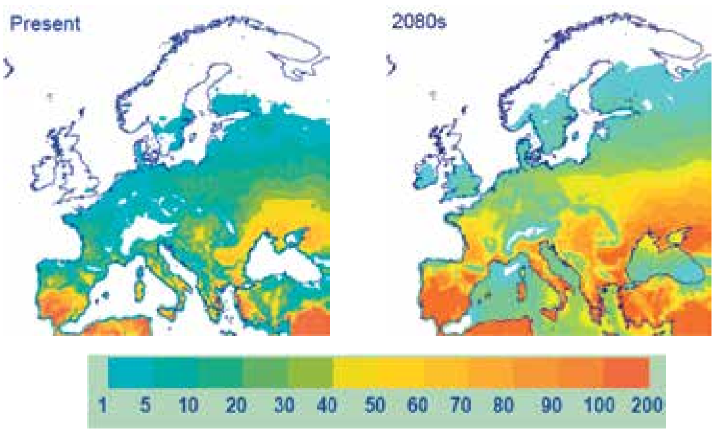


Fig. 13 - Areas of classes of days per year, with daily maximum temperatures higher than 30ºC in two periods: the present (left) and the 2080S (right). The heating effect is particularly noticeable in the Iberian Peninsula. (Grunderbeeck[112] and Tourre, 2008).

The uncertainties related to environmental temperature assessments are shown, for example, by the 2002 database of the MEDAR/MEDATLAS Group, where predicted data, at the end of the 21st century, for sea surface temperature (SST), temperature subsurface (T3D), and sea surface salinity (SSS) in the Mediterranean Sea and four of its sub-basins (Gulf of Lyon, Levante Basin, Adriatic Sea, and the Aegean Sea) are rather disperse. From various sources, such as projections of data measurements in the second half of the 20th century or from other models, although they indicate an increase in SST and SSS everywhere, they differ statistically at a 95% significance level.

In this context, the alkenone proxy method for SST assessment (Mix[113] et al., 2000) has shown opposite trends over the last 10,000 years. Negative trends are recorded in the north-eastern Atlantic and the western Mediterranean Sea, and positive trends characterize the SST records from the eastern Mediterranean Sea and the northern Red Sea.

[112] Van Grunderbeeck P., Tourre Y.M. (2008) - *Bassin méditerranéen: changement climatique et impacts au cours du XXIème siècle*. p.1.3-1.69. In: Thibault H.L. et Quéfélec S. (ss dir.): *Changement climatique et énergie en Méditerranée* (partie I, chap. 1), 558 pp.

[113] Mix, A.C., Bard, E., Elinton, G., Keigwin, L.D., et al. (2000) – Alkones and multiproxy strategies in peleoceanographic studies. Geochem. *Geophus. Goesysts*., vol 1, Paper number 2000GC000056. Published Nov 22.

5.2.2 - Changes in precipitation

Precipitation simulations indicated that the magnitude of observed terrestrial precipitation shows pronounced spatial variability as a function of time period and season, meaning low confidence in detecting anthropogenic trends in rainfall for the historical past. Precipitation and atmospheric and relative specific humidity decreased in the Iberian Peninsula and Greece throughout the second half of the 20th century (Grunderbeek and Tourre[114], 2008); Palutikof[115] et al., 1994; Palutikof[116] et al., 1996).

However, the precipitation's physical processes are very complex, and the respective modelling still needs upgrading at downscaling levels. One example of this complexity is that the Mediterranean Sea shows uneven and rugged coastlines with smaller seas, which require high-resolution observation for a deepened analysis. Some evidence emphasizes that the uncertainty of numerical models should not, however, be discarded.

The prospects for precipitation over the Mediterranean region in a warmer world are yet highly uncertain due to the general weakness of GCMs in predicting regional rainfall. Models offer conflicting evidence about how the precipitation may change on average in the Mediterranean region in a warmer world. Still, the prevalent tendency pointing to the 2020s suggests an overall decrease of between 1.5 and 7.3% by the 2020s (Rosenzwieg[117] and Tubiello, 1997). Global precipitation will likely increase at higher latitudes and decreases over subtropical land areas. With medium confidence, the most evident observed trend is a decrease in winter precipitation over the central and southern portions of MB since the second half of the 20th century (Fig. 14).

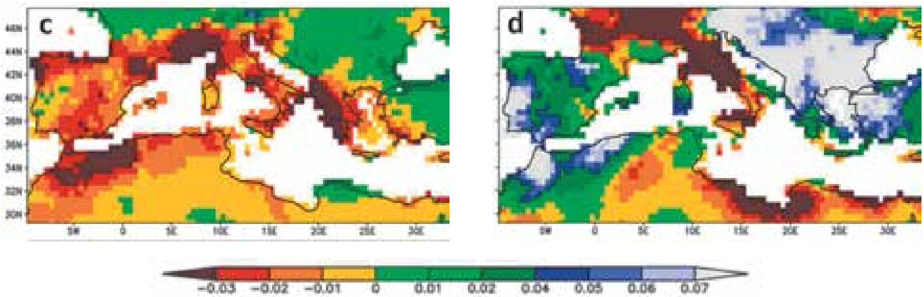


Fig.14 – Recent trends of observed changes in rainfall over land (mm $day^{-1}decade^{-1}$)
c) average for the period 1950-2018; d) for 1980-2018.
Data source: MeDEC (MAR 1), 2020

---

114 Krunderbeek, P., Tourre, Y (2008) – Mediterranean Basin: Climate Change and Impacts in the Mediterranean. Plan Bleu, Regional Activity Center, Sophia Antipolis. [access in https://eib.org/attachments/country/climate_change_energy_mediterranean_en.pdf]

115 Palutikof, J.P., Goodess, C.M., Guo, X. (1994) - Climate change, potential evapotranspiration and moisture availability in the Mediterranean basin. *International Journal of Climatology* [https://doi.org/10.1002/joc.3370140804]

116 Palutikof, J.P., Goodess, C.M., Watkins, S.J. and Burgess, P.E. (1999) - Developments in long-term climate change research. *Progress in Environmental Science* 1(1): 89-96

117 Rosenzweig, C., and F.N. Tubiello, 1997: Impacts of global climate change on Mediterranean agriculture: Current methodologies and future directions: An introductory essay. *Mitig. Adapt. Strategies Glob. Change*, 1: 219-232, [doi:10.1007/BF00517804].

Late simulation models from 2020 (Figs. 15 and 16) project for the MB, except for the northernmost regions (e.g., the Alps), a consistent decrease in precipitation in the 21st century, during the warm season from April to September, with the highest magnitude in summer. In northernmost regions, winter wetter conditions are projected.

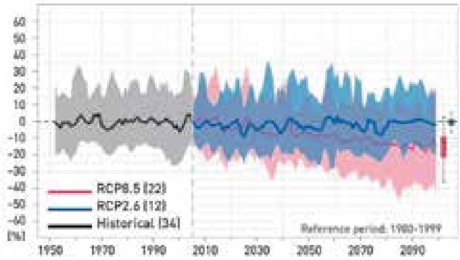


Fig. 15 – Projected land annual rainfall changes and anomalies in the Mediterranean Basin, (past reference 1980-1999)
Source: First Mediterranean Assessment Report, 2020

Climate projections for 21st century indicate also a predominant shift towards a precipitation regime of higher interannual variability, higher intensity, and greater extremes (especially in winter, spring, and fall, but not in the southern areas), decreased precipitation frequency and longer dry spells (especially in summer and in the southern countries).

Although forecasts are surrounded by uncertainty, the order of magnitude of the drying tendency of the late 20th century (Paeth[118] et al., 2016) appears to continue until the year 2100, with a reduction of annual precipitation of more than 100 mm. In many subregions of the Mediterranean basin, the aridification is in the order of more than 25% of present-day precipitation totals. In summer, the decrease is more expressed over southern Europe, in winter over the eastern Mediterranean and the Near East, with a slight and insignificant increase along the northern borders of the basin. Notably striking is the negative trend over the Iberian Peninsula.

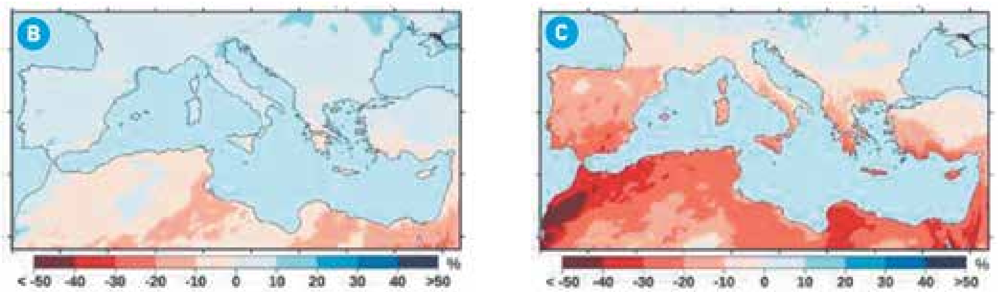


Fig. 16– Projected simulations in land annual rainfall anomalies at the end of the 21st century (2080-2099): B) for RCP2.6 and C) for RCP8.5
Data source: First Mediterranean Assessment Report, 2020

To complement this tendency of decrease rainfall, a reduction in water availability is also predicted. Water availability is determined both by water gains from precipitation and water

[118] Paeth, Heiko, Vogt, G., Paxian, A., Seubert, S. Jacobet, J. (2016) - Quantifying the evidence of climate change in the light of uncertainty exemplified by the Mediterranean hot spot region. [Version of Record: https://www.sciencedirect.com/science/article/pii/S0921818116300765]

losses through runoff and evapotranspiration. So, a future global temperature increase will increase evapotranspiration and, thereby, a loss in the available water. This implies that even when precipitation is forecasted to increase, available water can decrease if losses and the net budget become negative. On the other hand, if rainfall peak episodes increase, the likelihood is that water is not stored in the soil but lost as runoff. Evaluating moisture availability by GCMs is another difficult task because of the complexity of assessing potential evapotranspiration and the hydrological cycle (Rind[119] et al., 1990). In any case, the global influence of GHGs is likely to grow, and the long-term prospect is a tendency for dryness throughout the Mediterranean region.

5.2.3 - Changes in Extreme Events

Warmer conditions over the Mediterranean region should lead to increases of episodic events of extremely high temperatures and of decreases in extremely low-temperature events. Another view of the heatwaves of recent years is provided by categorizing months according to estimated levels of heat stress. July 2023 had a high number of days over Southern Europe[120] of four categories of heat stress: moderate (9.7%), strong (14.8%), very strong (10.0%) and extreme (1.7%). It also recorded the highest number of events of each stress category. Southern Europe is currently experiencing heatwave peaks, with parts of Greece, eastern Spain, Sardinia, Sicily, and southern Italy seeing temperatures above 45°C in July. As explained by Pappenberger[121], et al., 2023, the current extreme heat is due mainly to a slow-moving anticyclone, a high-pressure system, dominating the upper atmosphere over southern Europe. As it is known, anticyclones cause a downward motion of air, and as the air mass moves down, it is compressed and thus warmed. Such high-pressure systems are also associated with reduced cloud cover, allowing more solar radiation to reach the ground. This, in turn, provides for substantial heating of Earth's surface by the sun, heat that then moves upwards into the atmosphere. The long days and short summer nights mean that this heating effect is maximised. Advection of broadscale winds, such as hot air between two places, e.g., from northern Africa into Europe, can also contribute to heat waves.

An increase in drought periods is related to the previously mentioned high frequency of days during which the temperature would exceed 30 °C (Giannakopoulos[122] et al., 2005). Droughts are likely to become more frequent in areas experiencing a general decrease in precipitation. A tendency for the higher occurrence of extreme events has been noted since the mid-20th century. Globally, in this period, according to Hartmann[123]et al. (2013), it is very likely that the number of cold days and nights decreased and that the number of warm days and nights increased.

---

[119] Rind, D., R. Goldberg, J. Hansen, Rosenzweig, C. and Ruedy, R. (1990) - Potential evapotranspiration and the likelihood of future drought. *J. Geophys. Res.*, 95, 9983-10004, [doi:10.1029/JD095iD07p09983].

[120] The region designated to be "Southern Europe" mostly comprises parts of Europe that border the Mediterranean, but also includes northern parts of Morocco, Algeria and Tunisia, most of Türkiye and part of Syria. The region amalgamates the "South-West Europe" and "South-East Europe" regions discussed regularly in the corresponding hydrological bulletins by Copernicus Climate Changes Services.

[121] Pappenberger, F., Di Giuseppe, F., Buontempo, C., Emerton, E., Hewson, T., Di Napoli, C. et. al. (2023) - European heatwave July 2023. [www.ecmwf.int/en/about/media-centre/science-blog/2023/European-heatwave-july-2023]

[122] Giannakopoulos C., Bindi, M., Moriondo, M. LeSager, P. and Tin, T. (2005) – Climate Change Impacts in the Mediterranean Resulting from a 2 º C Temperature Rise. *Report WWF*, 66 pp.

[123] Hartmann, D. L., Klein Tank, A. M. G., Rusticucci, M., Alexander, L. V., Brönnimann, S., Charabi, Y. A. R., Dentener, F. J., et al. (2013) - Observations: Atmosphere and surface, pp. 159-254. In: *Climate Change 2013 the Physical Science Basis: Working Group I Contribution to the Fifth Assessment Report of the IPCC* (Vol. 9781107057999). Cambridge University Press.

Similarly, since 1950, the number of regions where heavy precipitation events over land have grown is higher than in regions where heavy precipitation events decreased. In Europe, increases in either the frequency or intensity of heavy precipitation prevailed.

The converse is true for areas where precipitation increases. It was reported that the probability of a dry spell lasting more than 30 days in summer in southern Europe would increase by a factor of between two and five, with the doubling of carbon dioxide (Palutikof et al., 1994).

In general, scientists expect more heavy rain events in a warmer world due to an intensification of the hydrological cycle. Most models suggest a general increase in precipitation intensity of between 10 and 30% at most latitudes for a doubling of carbon dioxide (Kattenberg[124] et al., 1996). Storminess may also increase, although this is less certain. Despite some uncertainties over how climate variability and extremes will change in the Mediterranean region, the overall picture suggests an increase in the frequency of extreme events and droughts in the western Mediterranean.

5.2.4 - Changes in Sea Temperature

Warming of the Mediterranean Sea surface is estimated at 0.4 ºC per decade between 1985 and 2006 (+0.3 ºC per decade for the western basin and +0.5 ºC per decade for the eastern basin). The temperature increases are not constant throughout the year but occur primarily during May, June, and July. Maximum increases of 0.16 ºC per year were found in June in the Tyrrhenian, Ligurian and Adriatic Seas and close to the African coast. The Aegean Sea shows maximum change in sea surface temperature during August.

The projections for 2100 vary between +1.8 ºC and +3.5 ºC on average (depending on the GHG emission scenario) compared to the 1961 and 1990 periods. The Balearic Islands, the northwest Ionian, the Aegean, and Levantine Seas have been identified as regions with maximum sea surface temperature increases. It is also likely that deep waters will warm more in the Mediterranean than in other oceans.

These predictions contain a degree of uncertainty due to recent in-depth studies of the ongoing abrupt change in the Atlantic meridional circulation (AMOC), a vast system of ocean currents that encompasses part of the Gulf Stream and other powerful currents. According to recent studies, AMOC has declined by 15% since 1950 and is at its weakest state in more than a millennium due to the faster-than-expected melting of Greenland's glaciers and Arctic ice sheets, which dumps freshwater into the sea and obstructs the sinking of saltier, warmer waters to the south, sparking speculation about its coming collapse. AMOC is a crucial component in global climate regulation, and its future collapse would have dire impacts on the climate in the North Atlantic region, as it is one of the most critical disruptors of the Earth's climate system (Ditlevesen[125]& Ditlevesen, 2023). A study last year, based on changes in sea surface temperatures, suggested that the tipping point could occur between 2025 and 2095 (van

---

[124] Kattenberg, A., Giorgi, F., Grassl, H., Meehl, G. A., Mitchell, J. F. B., Stouffer, R. J., et al. (1996) -Climate Models. Projections of Future Climate: in Houghton, J. T., Meira Filho, L. G., Callander, B. A., Harris, N., Kattenberg, A., and Maskell, K. (eds.), Climate Change *1995. The Science of Climate Change*, IPCC, Cambridge University Press, Cambridge, pp. 285-357.

[125] Ditlevesen, P., & Ditlevesen, Susanne (2023)- Warning of a forthcoming collapse of the Atlantic meridional overturning circulation. Nature Communications, 14:4254

Western[126] and Dijksttar, 2023). Knowing the importance of the heat storage and transport effects of the oceans, we can envisage the consequences of predicted changes in Earth's heat budget susceptible to drive significant shifts in temperature and precipitation patterns along the Mediterranean coast, potentially resulting in increased variations in temperature extremes, including heatwaves or cold spells and alterations in rainfall distribution, affecting agriculture and water resources management in the region. Variations in the AMOC can also influence the frequency and intensity of extreme weather events, such as storms, which can have significant implications for coastal communities, infrastructure, and agriculture.

Rising carbon dioxide (CO_2) concentrations lead to seawater acidification, and this trend will continue. The Mediterranean mean sea level has risen by 6 cm over the past 20 years. This trend is likely to accelerate (with regional differences) by the global rate of 43 to 84 cm until 2100, but possibly more than 1 m in the case of further ice-sheet destabilization in artic and in Antarctica.

Most impacts of climate change are exacerbated by other environmental challenges such as land use changes, increasing urbanization and tourism, agricultural intensification, overfishing, land degradation, desertification, and pollution (air, land, rivers and ocean). Sulphur dioxide (SO_2) and nitrogen oxide (NOx) have recently increased drastically, mainly because of shipping activity. Tropospheric ozone (O_3) concentrations increase due to pollution and warming, and high-level episodes will be more frequent in the future. Saharan dust transport is likely also to increase. The Mediterranean Sea is heavily polluted by multiple substances including plastic, emerging contaminants, heavy metals, fecal bacteria and viruses, all with expected increase in the future.

5.3 - Water Constrains in Mediterranean Basin

Existing studies foreseeing global warming of 2 ºC associated with a reduction in precipitation and increase evaporation are expected to reduce surface runoff and water yields in the Mediterranean region. In some countries, this could result in water demand exceeding available water supply with severe socio-economic negative impacts, mainly in the agriculture sector that is extremely sensitive to the hydrological cycle. Hence, knowledge of interannual climate variability inter alia water cycle variability is critical in agriculture activities, prediction, development, and policy instruments to guarantee satisfactory food supplies and sustainable land uses.

In the Mediterranean case, climate variation is closely related to the variability in the Atlantic sector, such as the North Atlantic Oscillation (NAO, 1996; Rodo[127] et al., 1997; Eshel[128] and Farrel, 2000). Past and future global climate changes possibly linked with the hydrological cycle can affect storm track characteristics (Arpe[129] and Roeckner, 1999), evapotranspiration changes and

---

[126] Van Western, R.M., and Dijkstra, H.A. (2023) – Assymetry of AMOC Hysteresis in a State-of-the-Art Global Climate Model. Geophysical Research Letters. Advancing Earth Space Sciences, 10 pp. [Doi: 10 1029/2023GL106088]

[127] Rodo, X., Baert, E. and F. A. Comin, F. A. (1997) - Variations in seasonal rainfall in southern Europe during present century: Relationships with the North Atlantic Oscillation and the El Niño Southern Oscillation. *Climate Dyn.*, 13: 275–284.

[128] Eshel, G., and Farrel, B. F. (2000) - Mechanisms of Eastern Mediterranean rainfall variability. *J. Atmos. Sci.*, 57: 3219–3232.

[129] Arpe, K., and Roeckner, E. (1999) - Simulation of the hydrologic cycle over Europe: Model validation and impacts of increasing greenhouse gases. Adv. Water Res., 23, 105–119.

overall land surface conditions (Reale[130] and Shukla, 2000; Bethoux[131] and Gentili, 1999). The Atlantic thermohaline circulation, by changing the characteristics of the water flux at the Gibraltar Strait, can also be impacted (Johnson[132] 1997).

The Mediterranean Sea is also an important source of atmospheric moisture. The characteristics of the local water budget, influence the amount of moisture that flows into northeast Africa and the Middle East (Peixoto[133]et al., 1982; Ward[134], 1998; Boukthir[135] and Barnier, 2000).

Several studies have dealt with the Mediterranean water budget, but results vary significantly among authors according to the specific methodology applied. For example, Boukthir and Barnier (2000) found that the difference between climatological means for evaporation (E) and precipitation (P) was about 650 mm yr^{-1} while Bethoux and Gentili (1999), reviewing several studies to reassess the Mediterranean water budget, indicate that having in consideration heat and salt budget, values of E-P will be in the range of 1050-1230 mm yr^{-1}.

These discrepancies reflect the uncertainties more generally associated with the estimates of the air-sea fluxes (WGASF[136], 2000) and indicate that further work is necessary to obtain a more realistic climatological picture of the Mediterranean hydrological budget, applicable, among other things, for validating global analyses and calibrating parameterizations. Most importantly, few studies concerning the Mediterranean have focused on the long-term variability of the flux of decreased precipitation and increased evaporation concerning global warming. More recently, Tsimplis[137] and Baker (2000) suggest that the sea level drop observed in the Mediterranean Sea since 1960 could be partly related to the influence of NAO on the air–seawater fluxes.

The availability of the atmospheric re-analyses in recent years have provided new information on the variability of the air–seawater fluxes at different timescales.

An intercomparison of climatological winter (December–February) and summer (June–August) precipitation in the Mediterranean region are depicted in Figs. 17 and 18 (Mariotti[138]et al., 2001).

In all seasons, the latitudinal gradient is the predominant precipitation feature in the Mediterranean region, with drier areas along the African coast and significantly wetter ones north

---

130 Reale, O., and Shukla, J. (2000) - Modeling the effects of vegetation on Mediterranean climate during the Roman classical period: Part II. Model simulation. *Global Planet. Change*, 25, 185–214.

131 Bethoux, J. P., and Gentili, B. (1999) - Functioning of the Mediterranean Sea: Past and present changes related to freshwater input and climatic changes. *J. Mar. Syst.*, 20: 33–47.

132 Johnson, R. G. (1997) - Climate control requires a dam at the Strait of Gibraltar. *Eos, Trans. Amer. Geophys. Union*, 78: 277–281.

133 Peixoto, J. P., Almeida M.de, R. D. Rosen, R.D. and D. A. Salstein, A. (1982) - Atmospheric moisture transport and the water balance of the Mediterranean Sea. *Water Resour. Res.*, 18, 83–90.

134 Ward, M. N., 1998: Diagnosis and short-lead predictions of summer rainfall in tropical North Africa interannual and multidecadal timescales. *J. Climate*, 11: 3167–3191

135 Boukthir, M. and Bernier, B. (2000) – Seasonal and inter-annual variations in the surface freshwater flux in the Mediterranean Sea from ECMWF re-analysis project. J. Mar. Syst., 24: 353-354.

136 WGASF, 2000: Intercomparison and validation of ocean-atmosphere energy flux fields. Final report of the Joint WCRP/SCOR Working Group on Air-Sea Fluxes, WCRP-112 (WMO/TD 1035), Geneva, Switzerland, 308 pp.

137 Tsimplis, M. N., and T. F. Baker, 2000: Sea level drop in the Mediterranean Sea: An indicator of deep-water salinity and temperature changes? *Geophys. Res. Lett.*, 27: 1731–1734.

138 Mariotti, A., Struglia, V., Zeng, Nibg and Lau, K.M. (2001) – The Hydrological Cycle in the Mediterranean Region and Implications for the Water Budget of the Mediterranean Sea. *J. of Climate*, 15:1674-1690

of the Mediterranean Sea. For the ocean areas, these datasets indicate that on average, the western Mediterranean sub-basin tends to be drier than its eastern counterpart.

Precipitation (Dec, Jan, Feb.) NCEP | Precipitation (Dec, Jan, Feb.) ERA

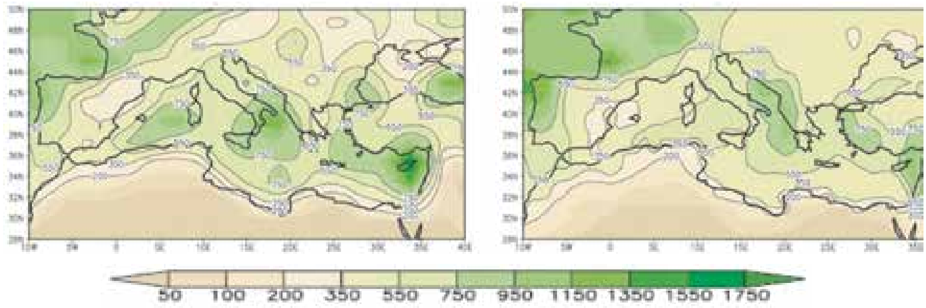


Fig. 17 – Climatological winter mean precipitation from National Centre for Environmental Prediction (NCEP) and European Centre for Median Range Weather Forecast – project ERA
Source: Adapted from Mariotti et al. (2001)

Precipitation (Jun, July, Aug.) NCEP | Precipitation (Jun, July, Aug.) ERA

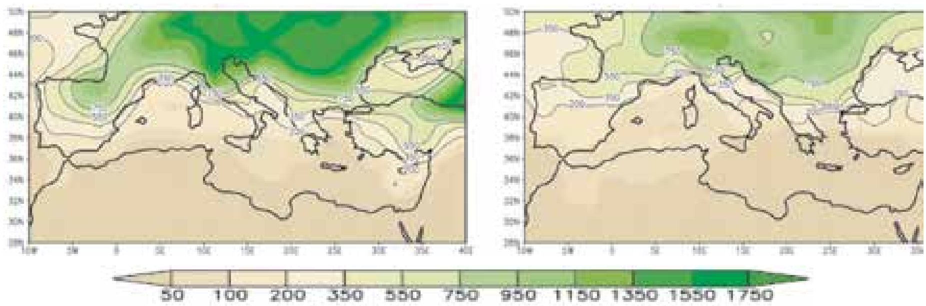


Fig. 18 – Climatological summer mean precipitation from National Centre for Environmental Prediction (NCEP) and European Centre for Median Range Weather Forecast – project ERA
Source: Adapted from Mariotti et al. (2001)

During summer, the whole Mediterranean region south of 40 ^{o}N is dry, receiving less than 200 mm yr^{-1}. Between 40^{o} and 44 ^{o}N, precipitation increases rapidly to approximately 550 mm yr^{-1}. CRU, CMAP, and ERA show local maxima of precipitation over the Alpine region and eastern Europe, but more abundant in CRU, especially over the Alps (over 1550 mm yr^{-1}).

In comparison, NCEP gives considerably higher summer precipitation over central and eastern Europe, a feature already discussed by Arpe[139] and Roeckner (1999).

Reanalysis of evaporation data from NCEP and ERA shows that evaporation over the sea is more intense during winter because of the stronger winds and drier air. Overland, winter

[139] Arpe, K., Roeckner, E. (1999) - Simulation of the hydrological cycle over Europe: Model validation and impacts of increasing greenhouse gases. *Advances in Water Resources* 23: 105-119

evaporation is less than 350 mm yr^{-1} in most areas. High values over Italy may be due to the low resolution available in the interface sea-land (Fig. 19).

On interannual to interdecadal timescales, during 1948-98, the Mediterranean atmospheric winter water deficit was positively correlated with the North Atlantic Oscillation (NAO). It has increased due to the long-term NAO positive anomalies since the early 1970s. Precipitation, which is also significantly correlated with the NAO, appears to be mostly responsible since no significant correlation is found for evaporation (Mariotti et al., 2001). Over the 50 years, the Mediterranean atmospheric water deficit increased by about 24% in the winter and 9% annually. Given that NAO influenced precipitation pattern anomalies, this change is likely to have occurred primarily north of 35 °N.

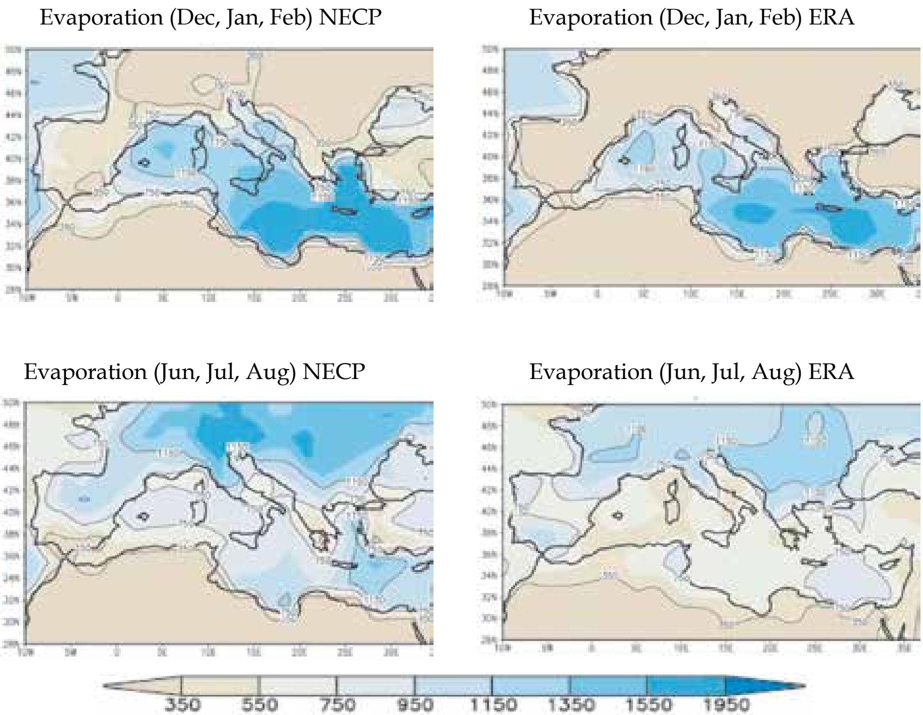


Fig. 19 – Climatological winter and summer mean evaporation in the Mediterranean area.

However, a complete understanding of natural Mediterranean drought variability and anthropogenically forced moisture trends requires comparisons with long-term variability unavailable from relatively short instrumental records. To this end, the paleoclimate community has been active throughout this region, developing estimates of Common Era drought variability from a variety of proxies, including tree ring analysis (Touchant[140] et al, 2014), sediment cores (Moreno[141] et al, 2012) and networks using multiple proxies [Carro-Calvo[142] et al., 2013).

To date, however, there is little consensus across these different records regarding the character and dominant drivers of drought variability across the basin over the last millennium. In particular, there are substantial uncertainties regarding how widespread droughts were in the Mediterranean, the magnitude and timing of long-term trends and centennial-scale variability (Wassenburg[143] et, al., (2013), and how seasonal signals and large-scale climate models are reflected in proxy reconstructions (Touchan et al., 2014; Seim[144] et al., 2015).

Recent decades have witnessed persistent, multiyear droughts in the Mediterranean that have spurred speculation that warming-induced drying trends may have begun to emerge. In the Old-World Drought Atlas (OWDA), these droughts are not coherent across the Mediterranean Basin but are instead highly localized in the WestMED region, Greece and the Levant.

Both WestMED (Touchan[145] et *al*., 2011) and Greece experienced significant droughts in the 1980s and 1990s. The driest period in the Levant began in 1998 and persisted through the end of the data set. The attempt was to place these most recent drought events within the context of the OWDA drought variability for the last 900 years.

Correlations between winter (January–March; JFM) and spring (April–June; AMJ) precipitation and the tree ring reconstructed summer (June, July and August; JJA) show that PDSI[146] are uniformly positive across MB. The strongest correlations with JFM precipitation are localized in Spain and Morocco in the western Mediterranean and the Levant region in the eastern basin. The AMJ precipitation correlations are more uniform and strongly positive across nearly the entire Mediterranean, suggesting that the summer season (JJA) soil moisture variability reflected in the OWDA and the underlying tree growth is driven primarily by spring precipitation (Touchan, et al., 2014).

Cook[147] et al. (2016) further investigate the nature and strength of drought variability across these regions through various spectral coherency analyses. The spectra of the WestMED and EastMED time series show significant power at interannual and decadal to multidecadal frequencies. Both regions have significant peaks at about 3-4 years, with EastMED additionally peaking at decadal frequencies and WestMED significant across a broader range of multidecadal

---

[140] Touchan, R., Anchukaitis, K.J.V., Shishov, V., Sivrikaya, F., Attieh, J., Ketmen, M., Stephan, J., I., et. al. (2014) - Spatial patterns of eastern Mediterranean climate influence on tree growth, *Holocene*, 24(4): 381–392.

[141] Moreno, A., et al. (2012), The Medieval Climate Anomaly in the Iberian Peninsula reconstructed from marine and lake records, *Quat. Sci. Rev*., 43: 16-32.
43, 16–32,

[142] Carro-Calvo, L., S. Salcedo-Sanz, S. and Luterbacher, J. (2013) - Neural computation in paleoclimatology: General methodology and a case study, *Neurocomputing*, 113: 262–268,

[143] Wassenburg, J. A., et al. (2013) - Moroccan speleothem and tree ring records suggest a variable positive state of the North Atlantic Oscillation during the Medieval Warm Period. *Earth Planet. Sci. Lett*., 375: 291–302-

[144] Seim, A., K. Treydte, V. Trouet, D. Frank, P. Fonti, W. Tegel, M. Panayotov, L. Fernández-Donado, P. Krusic, and U. Büntgen (2015), Climate sensitivity of Mediterranean pine growth reveals distinct east-west dipole, *Int. J. Climatol*., 35: 2503-2513.

[145] Touchan, R., Anchukaitis, K. J., Meko, D. M., Sabir, M., Attalah, S. and A. Aloui (2011), Spatiotemporal drought variability in northwestern Africa over the last nine centuries, *Clim. Dyn.,* 37(1–2): 237–252.

[146] PDSI - Palmer Drought Severity Index - Index that is based on the concept of water balance considering data on the amount of precipitation, air temperature and water capacity available in the soil; allows detecting the occurrence of drought periods and classifies them in terms of intensity (weak, moderate, severe and extreme).

[147] Cook, B. I., Anchukaitis, K.J., Touchan, R., Meko, D.M., and Cook. E.R. (2016), Spatiotemporal drought variability in the Mediterranean over the last 900 years, *J. Geophys. Res. Atmos*., 121: 2060-2074

bands. The two regions also overlap in their power at around 70 years, though EastMED is only marginally significant at the 90th percentile. A coherency spectra analysis between the two regional indices demonstrates highly significant coherence between the two regions on interannual and decadal timescales.

Over the period (1980–2012), Cook et al. (2016) identified major periods of persistent drought in all three of these regions: 1980-2009 (WestMED), 1984-2002 (Greece), and 1998-2012 (Levant).

Drought conditions in this region are likely to be further exacerbated with climate change (e.g., Gleick[148], 2014; Kelley[149] et al., 2015). Dealing with the consequences of aridification for societies and ecosystems in the region will require a multidisciplinary research, management, and policy approach (Sohl[150] and van Gleikel, 2014) on longer-term natural climate variability and aid in the interpretation of recent events and possible climate change contributions.

Although studies on precipitation and evaporation are an ongoing process, they show a marked variation. There is no doubt that the aquifer resources in the Mediterranean are scarce and unevenly distributed (72 to 74% are in the northern Mediterranean) and already in some areas insufficient to meet human and development needs.

The spatial distribution of water use per activity sector in the Mediterranean area is also heterogeneous. In southern and eastern countries, agricultural use reaches 76-79 % of the water resources. In the northern part, the four main economic activity sectors are much more balanced (18-36 %), with differences between countries. Because of this unequal availability, 180 million people in eastern and southern Mediterranean countries already suffer acute water scarcity (<1000 m3 $capita^{-1}yr^{-1}$).

Water scarcity in the Mediterranean has worsened in recent years, and the problem is severe. In a recent interview, Mastrojeni[151] (2021), Deputy Secretary-General of the Union for the Mediterranean, referring to the potential consequences for social and economic stability, says that "*predictions point to 250 million people in the Mediterranean basin living in shortages. The issue of water could prove to be a bomb issue in the Mediterranean*".

In the Mediterranean countries, water withdrawal for the agricultural sector is about 193 km^3yr^{-1} corresponding to about 64-69% of total water withdrawal (FAO[152] 2016). These amounts depend mainly on climate, from deficient levels in some Balkan countries to more than 80% in countries with an arid and semi-arid climate. The water quality used for irrigation is also a matter of concern, as low water quality may cause water-borne diseases and crop damage reducing agricultural production and quality.

The primary water user is agriculture, particularly on the southern and eastern rim. The percentage of irrigated land of the total cultivated area is 25% for the Mediterranean Basin (but more than 70% in Egypt, Israel, Lebanon, and Greece) and is currently increasing (≈ 21%), likely with higher rates under even drier climate conditions in the future. Water demand for both

---

[148] Gleick, P. H. (2014) - Water, drought, climate change, and conflict in Syria, *Weather Clim. Soc.*, 6(3), 331–340.

[149] Kelley, C. P., Mohtadi, S., Cane, M. A., Seager, R., and Y. Kushnir, Y. (2015) - Climate change in the Fertile Crescent and implications of the recent Syrian drought, *Proc. Natl. Acad. Sci.* U.S.A., 112(11): 3241–3246.

[150] Sohl, M., and van Ginkel, M. (2014), Drought preparedness and drought mitigation in the developing world's drylands, *Weather Clim. Extremes*, 3: 62-66

[151] Mastrojeni, Grammenos (2021) – O Mediterrâneo pode tornar-se um motor de caos e violência [The Mediterranean can become an engine of chaos and violence]. Interview with journalist Carla Tomás, Expresso, 4th December.

[152] FAO (2016) - AQUASTAT Main Database, Food and Agriculture Organization of the United Nations (FAO). [http://www.fao.org/nr/water/aquastat/data/query/ index.html?lang=en]

tourism and agriculture peaks in summer, potentially enhancing tensions and conflicts in the future. Municipal water use is particularly constrained in the south of the Iberian Peninsula and southern Mediterranean countries and will likely be exacerbated in the future by demographic and migration phenomena. In parallel, northern countries face additional risks in flood-prone areas where the population and urban settlements are rapidly increasing (MedEcC[153], 2020).

There is a trend in several Mediterranean countries towards the substitution of the irrigation surface with more efficient localized irrigation (Rodriguez-Dias[154] et al., 2011), e.g. in southern Spain, Portugal, and Maghreb oases (Ibáñez[155] et al. 2008). This trend is reflected in the National Strategy for Irrigation Water-Saving launched by the Moroccan government within the overall Green Morocco Development Plan. The trend towards more efficient irrigation systems may not have led to absolute water savings due to simultaneous changes towards water-demanding, more profitable crops (e.g., vegetables, blueberries and raspberries and semitropical fruit like avocado and mango) and/or expansion of irrigated areas (Ward[156] and Pulido-Velazquez, 2008). Yet, implementing water-saving irrigation systems has led to higher water productivity in terms of tons and revenues produced per unit of water applied. Implementing pressurized systems has also led to higher energy requirements and, thus, higher greenhouse gas emissions.

Daccache[157] et al. (2014) state that irrigation modernization in the Mediterranean could save 8 km3 of water per year at the cost of increasing CO2 emissions by 2.42 Gt CO2eq per year (+135%). The new development of solar pumps in drylands and desertic environments has created a substantial decrease in the fossil water table and increased risks of salinization (Gonçalves[158] et al., 2013) and increased the risk of accelerated land degradation that is already a constant in drier Mediterranean countries.

Climate change, in interaction with other drivers already mentioned (mainly demographic and socio-economic development), will have particularly negative consequences for the water cycle in the Mediterranean Basin, including reduced runoff and groundwater recharge, increased crop water requirements, and increased conflicts among users, and of overexploitation of already stressed ecosystems and degradation. These impacts will be much more important for global warming above 2 ºC.

Despite the uncertain projections, the available results suggest that, in response to changes in temperature, rainfall, and imbalances in water availability, it is anticipated a northward shift of homogeneous agro-climatic zones with a corresponding change in crop growth suitability in the

---

153 MedECC (2020) – Climate and Environmental Change in the Mediterranean Basin. Current Situation and Risks for the Future. First Mediterranean Assessment Report [Cramer, W., Guiot, J., Marini, K. (eds.)] Union for the Mediterranean, Plan Bleu, UNEP/MAP, Marseille, France, 632 pp.

154 Rodriguez-Dias; J.A, Pérez-urresttarazu, I., Camacho-Poyato, E. and Montesinos, P. (2011) – The paradox of irrigation scheme modernization: more efficient water use linked to higher energy demand. Spanis J. Agric. Res. 4: 1000-1008. [doi: http://dx.doi.org/10.5424/sjar/201-10904-492-10]

155 Ibáñez, J., Valderrama, J.M., Puigdefábregas, J. (2008) - Assessing overexploitation in Mediterranean aquifers using system stability condition analysis. *Ecol. Modell*. 218: 260 - 266. [doi: 10.1016/j.ecolmodel.2008.07.004].

156 Ward, F.A., Pulido-Velazquez, M. (2008) - Water conservation in irrigation can increase water use. *Proc. Natl. Acad. Sci. U. S. A.* 105: 18215–18220. doi: 10.1073/pnas.0805554105

157 Daccache A., Ciurana J.S., Rodríguez-Díaz, J.A., Knox, J.W. (2014) - Water and energy footprint of irrigated agriculture in the Mediterranean region. *Environ. Res. Lett.* 9, 124014. doi:10.1088/1748-9326/9/12/124014

158 Gonçalves, J., Petersen, J., Deschamps, P., Hamelin, B., Baba-Sy, O. (2013) - Quantifying the modern recharge of the "fossil" Sahara aquifers. *Geophys. Res. Lett.* 40, 2673–2678. doi: 10.1002/grl.50478

following decades (Cramer[159]et al., 2001; Ceglar[160] et al., 2019). This means that several regions of the Mediterranean may lose the ability to grow specific crops in favour of northern European areas. Ecosystems in these regions will become increasingly exposed to temperature and rainfall extremes beyond the climate regimes they are currently adapted to, which can alter agriculture structure, composition, and functioning.

In fact, there is mounting evidence that the warming is already modifying agricultural production systems and composition in Europe beyond phenological development stages. Extreme drought and heat stress had detrimental impacts on agricultural crop production in southern Europe, where moderate to extreme problems have been experienced (Zampieri[161] at al., 2017).

The observed warming has also promoted the shift of crop species to areas which were previously constrained by either a too-short growing season length (GSL) or by unreachable thermal requirements to finish the crop growth cycle (Hannah[162] et al., 2013; Marx[163] et al., 2017; Olesen[164] et al., 2017). A well-documented example is a shift in the climatic suitability for wine production, which was spatially mostly confined to Mediterranean, southern maritime, and Pannonian regions in Europe and which expanded in the recent period in several regions of central and northern western Europe (Spinoni[165] et al., 2015).

When it comes to incorporating information on different climate parameters to build a basis for predicting the effects of climate change on agricultural production processes, the information available is still particularly scarce. It is still a challenge to advise decision-makers, politicians, or businesspeople on how to plan to face the climate changes that requires integrated planning of the adaptation processes. Indeed, in simulation models, uncertainties tend to cascade onto one another, from estimating what future crop and processes should be adopted at the local level.

One may say that while a new set of climate change projections have been made available for the Fifth IPCC Assessment Report, most impact assessments are still based on the previous generation of climate projections of the Fourth Assessment as mentioned by Christensen[166] et al. (2007).

---

[159] Cramer, W., Bondeau, A., Woodward, F.I., Prentice, I.C., Betts, R.A. Brovkin, V., Cox, P.M., et al. (2001) - Global response of terrestrial ecosystem structure and function to CO_2 and climate change: results from six dynamic global vegetation models. Global Change Biol. 7:357-373

[160] Ceglar, A., Zampieri, M., Toreti, A., Dentener, F. (2019) – Observed Northward Migration of Agro-Climate Zones in Europe Will Further Accelerate Under Climate Change. *Earth's Future*, 7 (9): 1088-1101. https://doi.org/10.1029/2019EF001178

[161] Zampieri, M., Ceglar, A., Dentener, F. & Toreti, A. (2017) – Wheat yield loss attributable to heat waves, drought and water excess at the global, national and subnational scales. *Environmental Research Letters*, 12(6), 064008. [doi.org/10.1088/17488-932666/aa723b]

[162] Hannah, L., Roehrdanz, P. R., Ikegami, M., Shepard, A. V., Shaw, M. R., Tabor, G., et al. (2013) - Climate change, wine, and conservation. Proceedings of the National Academy of Sciences, 110(17): 6907–6912. [https://doi.org/10.1073/pnas.1210127110]

[163] Marx, A., Bastrup-Birk, A., Louwagie, G., Wugt-Larsen, F., Biala, K., Fussel, H. M., et al. (2017) - Terrestrial Ecosystems, Soil and Forests. [https://doi.org/10.1007/978-3-540-88246-6]

[164] Olesen, J. E., Niemeyer, S., Ceglar, A., Roggero, P. P., Lehtonen, H., Schonhart, M., & Kipling, R. - (2017). Climate change impacts on environmental systems: *Agriculture*. 1: 223–243, [https://doi.org/10.1007/978-3-540-88246-6]

[165] Spinoni, J., Vogt, J., & Barbosa, P. (2015). European degree-day climatologies and trends for the period 1951-2011. *International Journal of Climatology*, 35(1): 25–36. [https://doi.org/10.1002/joc.3959]

[166] Christensen, J.H., Hewitson, B., Busuioc, A., Chen, A., Gao, X. et al. (2007) – Regional climate projections. In: Solomon, S., Quin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L. (eds). Climate Change 2007:

Despite the Mediterranean climate uncertainties, there is a consensus that the 21st century is making the region a "climate change hot spot."

Uncertainties on regional climate projections in the 21st century in the Mediterranean basin are mainly due to numerical methods, and disaggregation techniques are not the same for all regional models. The uncertainties on the multiple domains impacted are because the interactions and feedback between the components of the physical systems that make up the climate (including the biosphere) are very complex and still require thorough studies.

The main conclusions of climate specialists converge on several general consensus, which are: i) even in the case that the European Union's objective of not exceeding an average global temperature increase of 2 °C has been achieved, in the Mediterranean basin, the temperature increases will probably be more significant than 2 °C. Thus, due to the ecological and socio-economic aspects of the area, the impacts will be more important than in many other regions of the world, and therefore, MB can be described as a "climate change hotspot"; ii) a general decrease in average precipitation over the entire Mediterranean basin is expected; iii) the most vulnerable Mediterranean zones are those of North Africa bordering the desert zones, the large deltas (those of the Nile, the Po, and the Rhône, for example), the coastal zones (northern and southern shores of the basin), as well as areas with strong population growth and socially vulnerable (South and East shore, dense cities, and suburbs) (IPCC AR4, 2007); iv) the impacts of climate change on the environment are already noticeable in the Mediterranean, themselves having already observed effects on human activities.

Additional consensus was reached regarding temperature increases and precipitation decreases over the entire MB: v) according to the 4th Report of the IPCC, under scenario A1B, the air temperature will experience an increase between 2.2 C° and 5.1 C° for the southern European countries and the Mediterranean region if we compare the period 2080 – 2099 with the period 1980 – 1999 (with some differences depending on the sub-regions); vi) the same projections give a considerable decrease in rainfall between -4 and -27 % for the southern European countries and the Mediterranean region (while the countries of northern Europe will experience an increase of between 0 and 16%). An increase in drought periods (associated with land degradation) resulting in a high frequency of days when the temperature exceeds 30°C is also predicted (Giannakopoulos et al. 2005); vii) extreme events like heat waves, droughts or floods could be more frequent and violent and viii) concerning the evolution of the sea level, more extended time series from satellite altimetry data, as well as an improvement of the in-situ network of tidal measurements, are still necessary to arrive at solid conclusions. Only a few climatological studies estimate that sea levels could rise by an average of 35 cm during the 21st century.

5.4 – Climate change and observed trends in Portugal

Climate change is a phenomenon that can affect daily rural communities directly or indirectly dependent on agriculture or forestry. The causes impacting negatively upon the agriculture activities in Portugal are related to climatic factors such as reduction and irregularity in rainfall, increase in temperature and the increases in the growing deficits of available water due to increased evapotranspiration, overexploitation of water and soils, the reduction of tree cover and land planning policies. Although our analysis focuses only on aspects of climate change, we

The Physical Science Basis, Contributing of Working Group I to the Forth Assessment Report of the Intergovernmental Panel on the Climate Change. Cambridge University Press, Cambridge UK. pp 847-940 should mention that the conditions of the structure of rural properties, the level of knowledge of entrepreneurs, agro-industrial chains and agricultural public policies will add positively or negatively to agricultural productivity.

Since rainfall is the water source in the hydrological cycle, quantifying long-term trends and abrupt changes in its series is fundamental to understanding freshwater vulnerabilities of availability for human needs and agriculture activities.

There has been a decrease in annual rainfall values over Portugal on Portugal's mainland. So, understanding past rainfall variations and anticipating the expected rainfall changes over different time scales are of the utmost importance because rainfall drives the hydrological processes (e.g., evapotranspiration and surface and groundwater flow) that affect the whole water resources system, the backbone of human activities.

Data shows a decrease in annual precipitation values on mainland Portugal, from about -20 to -25 mm/decade. The latter four decades have been consecutively drier, and the last 20 years have been stormy. Despite the great inter-annual variability, the downward trend is notorious; 6 of the 10 driest years (since 1931) occurred after 2000. 2005 was the driest, and 2007 and 2017 were the second and third driest, respectively. The reduction of precipitation values was verified in all year's seasons except for autumn. This reduction was particularly significant in spring (March, April, and May – MAM). The negative trend seems to be accentuating, and the periodicity of the drought is increasing. In fact, at the end of February 2022, 45% of the country was already under extreme or severe drought. It has not been 17 years since such a large portion of Portugal was in this situation. It also appears that January was the sixth driest in 90 years and the second worst since 2000.

If, on the one hand, there has been a decrease in the total annual rainfall, on the other hand, it is important to emphasize that the contribution of the days of intense precipitation for this total has been increasing, especially in autumn and in the southern region. In the opposite direction, the extreme phenomena of heavy rainfall show a trend descending in spring.

However, the general circulation models applied to different climate scenarios show significant differences, translating considerable uncertainties about future projections of the rainfall amounts and the scarcity of national data sets. Portela[167]et al. (2020) mentioned that most studies made in Portugal had been based on a few rain gauges or rainfall series with short time series, meaning that the values found show high variability. Increasing time series and a larger sample of rain gauges spread over the mainland to ascertain seasonal variations and trends in daily rainfall intensity frequency and duration of daily rainfall extremes are crucial for better rainfall predictions.

So, understanding past rainfall variations and anticipating the expected rainfall changes over different time scales are of utmost importance because the rainfall drives the hydrological processes (e.g., evapotranspiration and surface and groundwater flow), affecting the whole water resources system and negatively impacts all dependent activities on freshwater.

Portela et al. (2020) update previous studies covering all continental Portugal covering both a long period from 1913/1914 to 2018/19 and a large number of rain gauges (532), c.a. 6 gauges per 1000 km2, providing this way with a comprehensive assessment of the temporal and spatial rainfall variability over Portugal. The analysis period was partitioned into two sub-periods of 55

[167] Portela, Maria M., Espinosa, L. A. and Zelenakova, Martina (2020) – Long-Term Rainfall Trends and Their Variability in Mainland Portugal in the Last 106 Years. Climate 8(146): 1-18; doi:10.3390/cli8120146

years of observations (October 1913 - September 1967 and October 1968 - September 2019) to determine if rainfall trends became more pronounced in southern Portugal, a more vulnerable region, as shown in Fig. 20.

The main findings of this research evidenced a widespread decrease in the rainfall over Portugal, especially in the final sub-period (1968/69 to 2018/19), which also resulted in a more pronounced asymmetry between a still relatively wet North and a dry South. So far, changes showed trend mean values of -4.27 mmy^{-1} for the 106-year period compared with 0.89 mmy^{-1} for 1913/14 - 1967/68 and -11.42 mmy^{-1} for 1968/69 - 2018/19. Compared to the initial 55 years, the values highlight the widespread extent of the decreasing trends in the last 51 years.

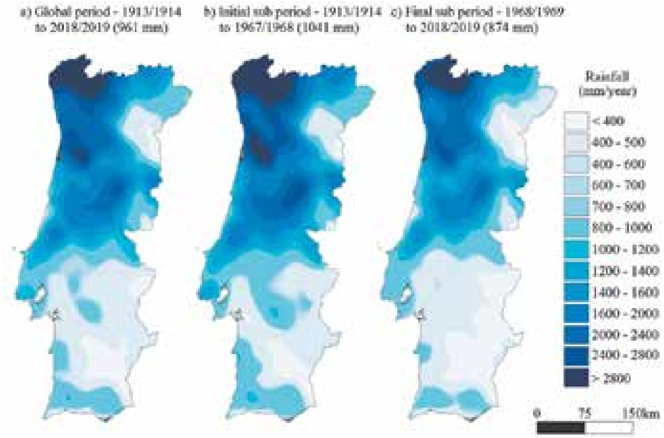


Fig. 20 – Mean annual rainfall in Portugal for the global period (106 hydrological years)

Such decrease in absolute terms has been progressively affected by the more contributing months of the wet season and their relative contribution to annual rainfall, thus intensely conditioning the intra-annual rainfall pattern. This behaviour is particularly pronounced before the long dry season starts, i.e., in the last wet period of the hydrological year (Q2, January to March), a fundamental period for replenishing water in the soil and the artificial reservoirs.

The analysis throughout the 106-year period showed that the amplitude of the rainfall decrease has gradually narrowed, which means less uncertainty about its behaviour. For the months of the rainy season, except for October, the trends are consistently negative. Such homogeneous behaviour indicates the country's vulnerability to the rainfall decrease, given it is not expected that some regions may become wetter, allowing transfers of water to counterbalance those becoming drier.

Portela et al. (2020) study shows that the country experienced a mean annual rainfall decrease from one sub-period to another is almost 170 mm. In the northwest, wettest region, such decreases exceed 500 mm. Furthermore, it shows that the same dimensionless rainfall reduction affects both wetter and drier areas, meaning that some of these last regions are becoming much drier than the former.

Such behaviour reinforces the difference between a less wet north and a drier and arid south. This agrees with the global assessment findings of wetting/drying trends during the period 1948–

2005 of Greve[168] et al. (2014) that identified the southwest regions of the Iberian Peninsula as one hot spot of the pattern "dry get drier". From the perspective of agriculture activities, it is also worth noticing the differences amongst quarters (Q1- October to December; Q2 – January to March; Q3 – April to June; Q4 – July to September) (Table 5). Data shows that wet semester (S1) accounts for about 74% of the annual rainfall.

The Palmer Drought Severity Index (PDSI) analysis shows an aggravation of the drought intensity from decade to decade (Fig. 21), from February to April, with the decade of 1991-2000 registering a significant increase in the intensity of the index.

Table 5 – Intra-annual average rainfall distribution in the period 1913/14 – 2018/19 expressed in mm and by their relative contribution to the mean annual rainfall (P/Pyear).

Quarters	Rainfall, P mm	P/Pyear (-)
Q1	360	0.375
Q2	348	0.362
Q3	183	0.180
Q4	70	0.073
Semesters		
S1	708	0.737
S2	253	0.263
Mean annual rainfall	961	1

Data Source: Portela et al. (2020)

The analysis of the Periods of Intense Drought (PID index), which analyses the indicators of the various classes of drought (normal, weak, moderate, severe, and extreme), shows that in the driest years of the series, started in 1941, 56% of the territory came to be in severe drought and 24% in extreme drought at the end of the dry period of 1945. Since 1980, however, there have been nine occasions when more than 10% of the mainland has been in a situation of extreme drought and four in more than 75 % of mainland Portugal was in severe or moderate drought (Pires[169], 2003).

For the viability of agriculture, it is essential to know the occurrence of droughts and their duration. In the case of Portugal, it has been verified that the frequency and duration of drought occurrences have increased, affecting growing areas of the national territory (Fig. 21).

[168] Greve, P.; Orlowsky, B.; Mueller, B.; Sheffield, J.; Reichstein, M.; Seneviratne, S.I. (2014) - Global assessment of trends in wetting and drying over land. *Nat. Geosci.* 7: 716–721.

[169] Pires, V. (2003) – *Frequência e Intensidade de Fenómenos Meteorológicos Extremos Associados a Precipitação*. Dissertação para a obtenção do grau de Mestre em Ciências e Engenharia da Terra, Faculdade de Ciências da Universidade de Lisboa, 98 pp.

Figure 22 shows that the 11 drought situations referred to as the most intense and extended periods were 1943-1946, 1980-1983, 1990-1992, 1994-1995, 2004-2006, 208-209, 2011-212, 2014-2015 and 2016-2017.

It is noteworthy that the duration of the 1943-1946 drought was 38 months in “Castelo Branco” and Oporto, 1980-1983 lasted 39 months in Alvega and 36 months in Sagres, 1991-1992 lasted 34 months in “Penhas Douradas” and 30 months in “Miranda do Douro” and the 2004-2006 period took effect 36 months in Braga, 35 months in “Amareleja” and 33 in “Beja”, 2011-2012 took 11months and affected 80% of the mainland and the last drought of the period 2016-2017 last eight months and affected 97% of the continent. The 1943-1946 drought was the longest in the past 70 years.

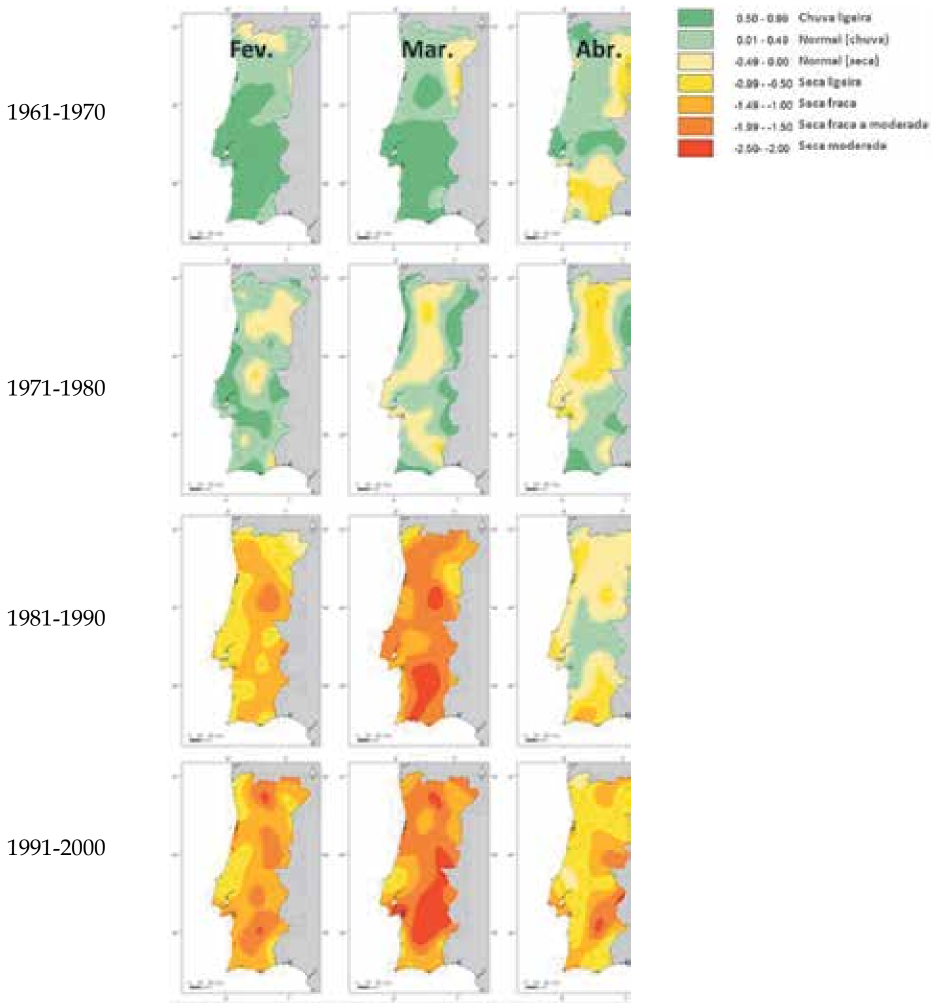


Fig. 21 - Monthly average of the PDSI in the decades 1961-1970, 1971 1980, 1981-1990 and 1991-2000 in mainland Portugal (Source: Pires 2003).

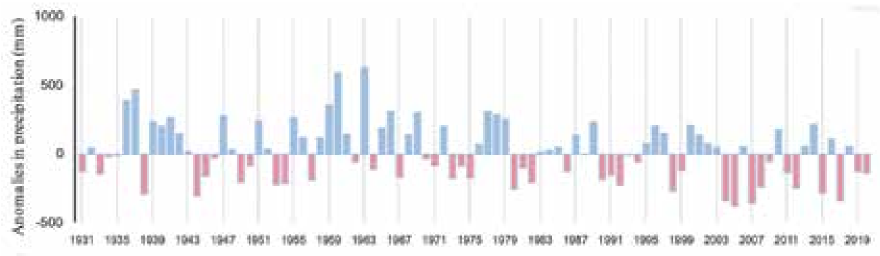


Fig. 22 – Representation of precipitation anomalies in Portugal in relation to normal (1971-2000)
Source: Instituto Português do Mar e da Atmosfera (IPMA)

Data in Fig. 22 shows that of the 11 drought situations referred, the most intense and extended were 1943-1946, 1980-1983, 1990-1992, 1994-1995, 2004-2006, 2008-2009, 2011-2012, 2014-2015 and 2016-2017. It is noteworthy that the duration of the 1943-1946 drought lasted 38 months in Castelo Branco and Oporto, 1980-1983 lasted 39 months in Alvega and 36 months in Sagres; In 1991-1992 drought lasted 34 months in Penhas Douradas and 30 months in Miranda do Douro. In the 2004-2006 period, the drought lasted 36 months in Braga, 35 months in Amareleja and 33 months in Beja; in 2011-2012, last 11months and affected 80% of the mainland, and the drought of the period 2016-2017 lasted eight months and affected 97% of the continent. The 1943-1946 drought was the longest in the past 70 years. The absence of rainfall, especially in the South, and the increased number and duration of rainfall anomalies will be the new normal in the South (Pires[170], 2019).

Regarding the percentage of affected territory, the drought of 1943-1946 affected 52% of the territory for more than 24 months. In 1980-1983 and 2004-2006, the percentage of affected territory was 27%. We should note that droughts have become more frequent in this century, and their effects have been felt in almost the entire continental territory. In fact, the droughts of 2004-2005 and 2016-2017 affected, respectively, 80% and 97% of the Portuguese mainland.

As shown, the negative trend of rainfall has increased in the last 5 years and in the first two months of 2022 the severe and extreme drought affects already 45% of the country requiring a set of conservative integrated measures to cope with climate change.

Precipitation projections in Portugal regions for the end of the 21st century where main dams are identified point to a decrease in annual precipitation in mainland Portugal of 5 to 10% in the intermediate scenario RCP4.5 and 10 to 30% in the case of the more severe scenario RCP8.5. The most significant percentage reduction is predictable in the southern regions (Fig. 23).

Regarding the percentage of affected territory, the drought of 1943-1946 affected 52% of the territory for more than 24 months. In 1980-1983 and 2004-2006, the percentage of affected territory was 27%. We should note that droughts have become more frequent in this century, and their effects have been felt in almost the entire continental territory. In fact, the droughts of 2004-2005 and 2016-2017 affected, respectively, 80% and 97% of the Portuguese mainland.

As regards temperature, projections made according to General Circulation Models (GCMs) show their good adherence in large-scale circulation reproduction. Still, its performance and detail in regional climate reproduction are poor due to its low resolution, especially in areas with accentuated and complex orography (Font-Tullot[171], 2000).

---

170 Pires, Vanda (2019) – Grupo de Trabalho da Seca, Relatório [Drought Working Group, Report], IPMA

171 Font-Tullot, Inocencio (2000) – *Climatologia de España y Portugal* (2 ed.). Ediciones Universidad de Salamanca. 422 pp.

The mean annual temperature values vary from 6 ºC in the Central interior highlands (Serra da Estrela) to a maximum of 17 ºC along the southern coastline. The mean monthly air temperature values vary regularly throughout the year, with the maximum values registered in August and the minimum in January.

In the summer, the maximum temperature oscillates between 20 ºC and 25 ºC on the western coast and is above 30 ºC in the interior central region and the south (Alentejo). The mean values of minimum temperature vary between below 0 ºC in Serra da Estrela and the interior mountainous regions and 9 – 10 ºC for the Southern coastline (Fig. 24).

Since the beginning of the 21st century, almost every year has recorded average temperatures close to or above the average values for 1971-2000 (except 2002, 2008 and 2012).

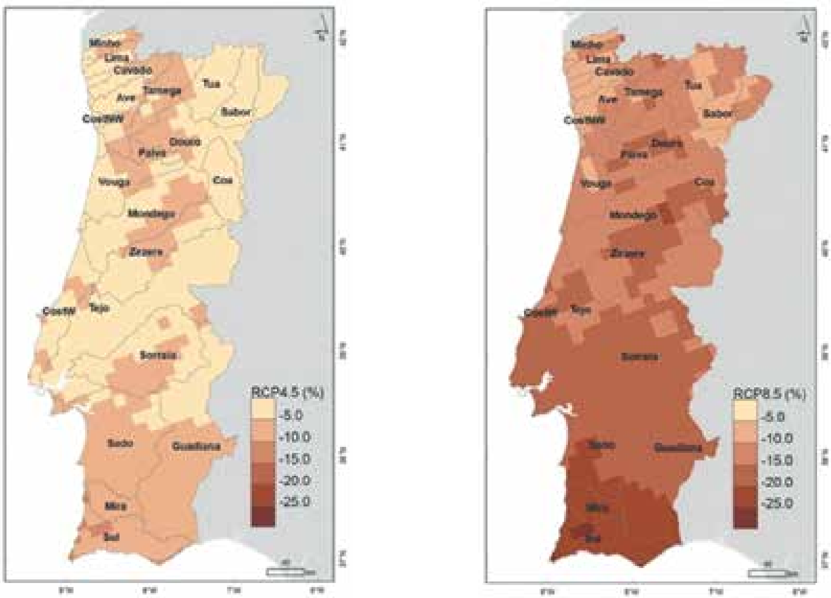
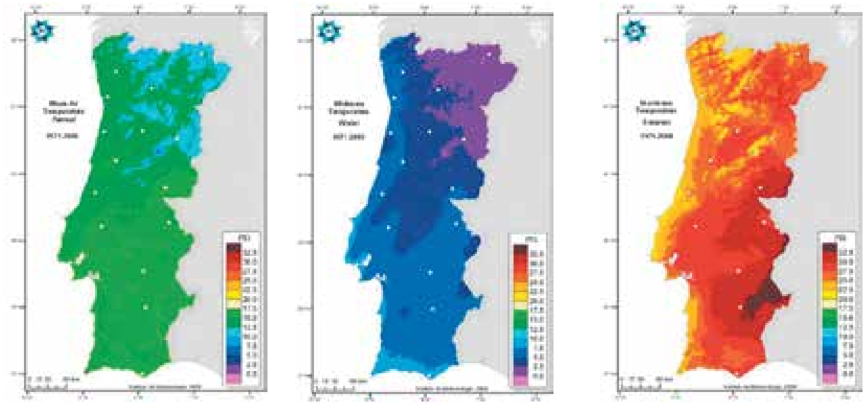


Fig. 23 - Scenarios of annual precipitation in mainland Portugal for RCP4.5 and RCP8.5 (Ensemble - Portal do Clima) in the period 2071-2100 (differences in relation to the average values in the 1971-2000 period). [Source: Pires[172], Cota and Silva (2018)]

[172] Pires, V. C, Moura-Cota, T., Silva, Álvaro (2018) – Alterações observadas no clima atual e cenários climáticos em Portugal continental Influência no sector agrícola, pp. 57-67. in: Cultivar. Cadernos de Análise Prospetiva. Nº 12, Lisboa



A B C

Fig. 24 – A) Mean annual air temperature; B) mean minimum annual air temperatures in winter; C) mean maximum temperature in summer (1971-2000)

Source: Fifth National Communication to the United Nations Framework Convention on Climate Change. Agência Portuguesa do Ambiente, 2010

The analysis of the evolution of the average temperature since the 70s shows that Portugal's temperature has been rising at 0.36 ºC/decade, doubling the world rate. In the last 78 years, 1997 has been the hottest year, and seven of the ten hottest years occurred after 1990 (1997, 1995, 1996, 2006, 1990, and 2003).

The data available at IPMA show that, since the beginning of the 21st century, almost every year recorded average temperatures close to or above the average values for the 1971-2000 period (except 2008 and 2012) and rainfall below 120% about normal for the reference period 1971-2000 (except 2010 and 2014). Temperature variability and anomalies are depicted in Fig. 25.

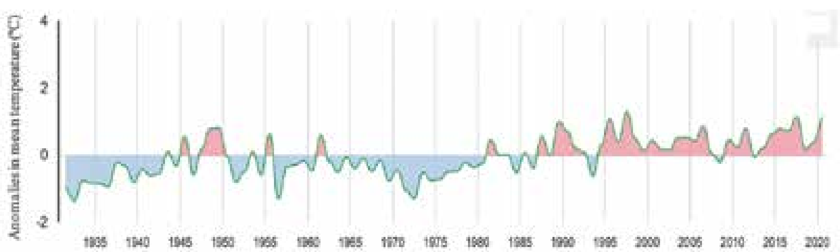


Fig. 25 - Annual average temperature anomalies in mainland Portugal in relation to the 1971-2000 normal value (Source: IPMA)

Several outbreaks of heat waves have particularly hit 2023, and July was the hottest month ever recorded. The global average temperature temporarily exceeded 1.23°C above the pre-industrial level during the first and third week of the month (Copernicus Climate Change Service).

In general, in aggregate terms, we may say that mensurable changes in precipitation patterns from 1970 models project a drier climate, with a shorter and wetter rainy season followed by a long dry summer. The projected reduction in mean precipitation will likely affect the country's southern regions more, which already experience a water shortage and sizeable interannual variability. Projected changes in rainfall seem to be related to slight changes in the large-scale circulation patterns in the Iberian/Atlantic region, driven by corresponding changes in the North Atlantic circulation.

In those scenarios, Portugal's increase in near-surface temperature is far higher than the predicted changes in global mean temperature, anticipating a significant shift in all temperature-related climate indices. Impacts are higher in summer and autumn and on the country's interior.

In general terms, we can say that since the 70s, the average temperature has risen in all Portuguese regions at around 0.3 ºC / decade. We should note that of the ten warmest years, seven occurred after 1990 (Pires, 2019).

5.5 – Bioclimatic regions in Portuguese territory

Although the Portuguese territory is small, and the Mediterranean Sea does not border its coast, truth is that climates and microclimates coexist there with different gradations ranging from the typical Mediterranean to the Atlantic, that is, from the olive and fruit trees, the holm oak and woody persistent leafy trees species adapted to dryness, to the region of softwoods and deciduous hardwoods, producing woods like Pinus pinaster and some oaks with Castanea sativa in the middle. Santa-Rita[173] (1982) reminds us that in Estremadura (North-South axis), 38% of plant species come from Central and Western Europe, and 62% belong to the Mediterranean flora.

Albuquerque[174] (1954), in a Phyto-ecology work on the entire Portuguese territory, divided the country into three large zones, where the effects of the Atlantic (A), Mediterranean (M), Oro-Atlantic (OA) and Iberian (I) climatic poles are felt. These areas were characterized as follows:

A - Atlantic - Rainy climate, with moderate winter and mesothermal summer. It is located throughout the country's Northwest and has *Quercus robur* as an indicator species.

M - Mediterranean and its eumediterranean expression - low rainfall, mild winter, and dry and macro-thermal summer. It is well represented in the country's south, and its influence is reduced as one increases in latitude and altitude until it almost disappears in the Minho region, above 900 m. Its indicator species are the cork oak, the carob tree, the almond tree, and the fig tree.

I - Iberian - Continental climate, little rainfall, cold winter and mesothermal summer. It is presented in the highlands of the main existing mountain systems north of the Tagus River. The indicator species is *Betula pubescens*.

According to the same author, there is still, in the extreme southwestern Portuguese territory, next to the Sagres peninsula, a tenuous representation of the Atlantean-Subtropical or Macaronesia domain, which has the *Myrica faya* as an indicator species.

We can say that the four poles, as described by the author, are not enough to characterize the very diverse mosaic of Portuguese space. However, like Ribeiro[175] (1970), we can say that the

---

[173] Santa-Rita, Gonçalo (1982) – *Portugal, a expressão da paisagem*, Lisboa, Terra Livre

[174] Albuquerque, J. de Pina Manique e (1954) – Carta Ecológica de Portugal, Lisboa, Rep. Est. Inf. Prop. Ministério da Economia

[175] Ribeiro, Orlando (1970) – Portugal, o Mediterrâneo e o Atlântico, Lisboa, Livraria Sá da Costa

Mediterranean component has a more decisive action than the Atlantic one, extending practically to the entire country below 900 m of altitude.

From the works of various authors, from historical-geographical observations to the zoning of woody species, especially oaks, to ecological factors, the division of the territory into two components stands out: Mediterranean and Atlantic. As Guerreiro[176] (1999) says, even the least attentive inhabitant of the flat landscape of the dry stubble of the south, when visiting the running water meadows of the northern half slopes, realizes that he is faced with two different realities: the Minho, a region with a predominantly Atlantic climate where "winter arrive, gloomy and dark, with its stormy procession of rains, gales and darkness", and the south, where the climate is milder, the winters are less severe, with almost no neither snow nor frost and increased atmosphere luminosity.

The Mediterranean climate is characterized, although not very rigorously, by some numerical indicators presented by bioclimatologists. Perhaps in this domain, the Köpen classification is the one that provides the best information, "the most perfect," in the words of Peixoto[177] (1987), although Emberger's rainfall coefficient is of great interest.

Thus, as illustrated in Fig. 26, we can see that in the bioclimatic regions of Portugal, according to the Köppen-Geiger classification, most of the continental territory is also well represented along the Mediterranean border of Europe. We thus have a temperate climate characterized by the occurrence of dry summers (Mediterranean climate), subtype Cs, with the following variants: temperate climate with dry and mild summers (Csb) in almost all regions from the north and west coast to the south; hot and dry temperate summer (CSA) in the interior regions of the Northeast, as well as in the southern regions of the mountain system; in a small region to the southeast, it has an arid climate (B), a subtype of the cold steppe of mid-latitudes (BSk).

Fig. 26 – Portugal's and European Mediterranean Köppen-Geiger climate classification
Source: a) IPMA; b) Noceand[178]and Santini (2018)

Analysing the photoperiod, we notice that it is not significantly longer in the south than in the North. The latitude difference is only five degrees (37º to 42º). In fact, if in Faro the shortest day

[176] Guerreiro, Manuel G. (1999) – O Homem na perspectiva ecológica, Faro, Fundação para o Desenvolvimento da Universidade do Algarve, 462 pp.

[177] Peixoto, J. Pinto (1987) – *O sistema climático e as bases do clima*, Lisboa, Sec. Est. Ambiente e Recursos Naturais.

[178] Noceand , S. and Santini, Monia, (eds) (2018) - Mediterranean Forest Ecossystem Sevices and their Vulnerability, FoundationEuro-Mediterranean Center on Climate Change (CMCC), 36 pp

of the year is 9.9 hours and in Bragança 9.7 hours, the longest day of the year in the first city is 14.4 hours, and in the second 15.5 hours, that is little more than an hour difference. The cloudiness, in fact, greatly alters the global radiation received in the North of the country and even more when in areas of medium and high altitude.

It should be noted that, in any case, those areas, despite the contribution of the numerical formulations at their base, nor even the geographical location, are not enough to characterize the Mediterranean climate. The extreme climatic complexity of a place, whose expression, in Braudel's[179] (1983) words, "*deforms itself and is steppe, desert or forest as a result of the sun, overlap and mixed nature of winter rain and summer drought*", intervening by combination, in the composition of the "*thousand climates*" that, in mosaic, characterize the Portuguese land space.

Despite the limitations mentioned, and in global terms, we can say that the Mediterranean presence in Portugal falls between the limit of the olive tree and the large palm groves (*Laurentum* level), encompassing the vine, fig, carob, pomegranate trees, orange and lemon, cork oak, holm oak, and the small broom palm (*Chamaerops humilis*), the only one of European expression.

But as Guerreiro (1999) said in the characterization of the Mediterranean, "*more than that is necessary; it is the men, whether in their daily life, in agricultural activity, or in leisure, who best know how to understand and define it*". It is often said the Mediterranean is not described; it is how it is felt.

5.6 - Interlinks of climate change and land use

In this review, we will only address some aspects of evidence based on observations of more recently emerging land-induced climate impacts (Forzieri[180] et al., 2017), particularly on the foreseeable implications of rising global temperature and changing rainfall patterns in terrestrial ecosystems and crop yields.

Land is the basis of all terrestrial life and the operative link between biodiversity loss and climate change and, therefore, must be the primary focus of any meaningful intervention to tackle these intertwined crises. Soils are finite in extent, variable over time and space, and prone to alterations by natural and anthropogenic perturbations.

The uncertainty of climate change and the complex feedback loops between climate and land mean that agriculture is subject to amplified levels of risk that need to be addressed and managed. The need for a global vision regarding the convergence of factors that exert unprecedented pressure on land and water resources, leading to a set of human impacts and shocks in the supply of agricultural products, notably food, is fundamental to support any integrated action of an intervention. The FAO[181] report (2022) argues that a sense of urgency needs to prevail over a hitherto neglected area of public policy in favour of human well-being and caring for the long-term future of the land, soil, and water.

The evidence of the variability effects of climatic parameters on agriculture, namely its implications on crop yield and food security, and the fact that agricultural activities are a significant contributor to GHG emissions have long been known, especially from early

[179] Braudel, Fernand (1983) – *O Mediterrâneo e o Mundo Mediterrânico*, Lisboa, Publicações Dom Quixote

[180] Forzieri, G., Alkama, R., Miralles, D.G. and Cescatti, A. (2017) - Satellites reveal contrasting responses of regional climate to the widespread greening of Earth. *Science*, 356: 1180-1184

[181] FAO (2022) -The State of the World's Land and Water Resources for Food and Agriculture – Systems at the breaking point. Main Report, FAO, Rome 393 pp.

paleoclimate information, namely the effects of human-induced deforestation. Land clearing, primarily for agriculture, has accounted for about a third of global anthropogenic carbon dioxide (CO_2) emissions in recent decades (Denman[182] et al., 2007). Hence, the evolution of cropland and its implications on food vulnerability are also essential components of future climate change and must be considered in future strategies to mitigate greenhouse gas emissions (Wise[183] et al., 2009).

Socio-economic factors, such as the growing demand for food, feed, and wood products, are among those that weigh the most in the changes that have taken place in land use and in the over-exploitation to which it has been subjected and in its consequent degradation.

There is high confidence that land degradation and climate change, individually and in combination, have profound implications for natural resource-based livelihood systems and societal groups. The number of people whose livelihood depends on degraded lands has been estimated to be about 1.5 billion worldwide. People in degraded areas who directly depend on natural resources for subsistence, food security and income, with limited adaptation options, are especially vulnerable to land degradation and climate since land degradation reduces productivity and increases the workload of managing the land, affecting women disproportionally in some regions. Land degradation and climate change act as threat multipliers for already precarious livelihoods, leaving them highly sensitive to extreme climatic events, with consequences such as poverty and food insecurity that strongly drive migration, conflict and loss of cultural heritage. Changes in vegetate cover and distribution due to climate change increase the risk of land degradation in some areas and will have detrimental effects on livelihoods, habitats and infrastructure through increased rates of land degradation.

Land degradation is a recognized driver of climate change through the emission of greenhouse gases (GHGs) and reduced carbon uptake rates. Since 1990, at the world level, the forest area has decreased by about 3%, with net decreases in the tropics and net increases outside the tropics. Compared to carbon stocks before deforestation, lower carbon density in re-growing forests results in net emissions from land-use change (IPPC). Forest management that reduces carbon stocks of forest land also leads to emissions, but global estimates of these emissions are uncertain. Cropland soils have lost 20-60% of their organic carbon content before cultivation, and soils under conventional agriculture continue to be a source of GHGs. There is high confidence that the land degradation processes, deforestation, increasing wildfires, degradation of peat soils, and permafrost thawing contribute most to climate change by releasing GHGs and reducing land carbon sinks following deforestation. Agricultural practices also emit all kinds of GHGs from soils, and these emissions are exacerbated by climate change. Conversion of primary to managed forests, illegal logging and unsustainable forest management result in GHG emissions, and there is high confidence that it can have additional physical effects on the regional climate, including those arising from albedo shifts (medium confidence). These interactions call for more integrative climate impact assessments.

---

[182] Denman, K. L., et al. (2007) - Couplings between changes in the climate system and biogeochemistry, in Climate Change: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, (ed.) S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor, and H.L. Miller, Cambridge Univ. Press, Cambridge, U.K.

[183] Wise, M. A., Calvin, K., Thomson, A., Clarke, L., et al. (2009), Implications of limiting CO_2 concentrations for land use and energy, *Science*, 324: 1183–1186, [doi:10.1126/science.1168475].

Changes in crop use (Tribouillois[184] et al., 2018), especially in forest cover, affect the balance between sink and release of CO_2 and the emissions of biogenic volatile organic compounds (BVOCs) in the atmosphere (Doblas-Miranda[185] et al., 2017).

Interrelationships between impacts of climate change and land cover and main drivers are depicted in Fig. 27.

Land use changes by modifying surface albedo also entails a highly potential impact on climate change (Benas[186]and Chrysoulakis, 2015). Changes in the forest cover due to inappropriate management, and socio-economic issues could reduce albedo (Rotenberg[187] and Yakir, 2011; Godinho[188] et al., 2016), while wildfires increase radiation emissions to the atmosphere (Sanz-Sanchez[189] et al., 2015), with contrasting effects on local climate. Agricultural cover may decrease or increase albedo by the farming technology adopted (Giannakopoulou[190] and Toumi, 2012; Carrer[191] et al., 2018), while urban sprawl increases radiation absorption and local temperature (Salvati[192] et al., 2019).

---

[184] Tribouillois, H., Constantin, J., Justes, E. (2018) - Cover crops mitigate direct greenhouse gases balance but reduce drainage under climate change scenarios in temperate climate with dry summers. *Glob. Chang. Biol.* 24: 2513–2529. [doi: 10.1111/gcb.14091]

[185] Doblas-Miranda, E., Alonso, R., Arnan, X., Bermejo, V., Brotons, L. et al. (2017) - A review of the combination among global change factors in forests, shrublands and pastures of the Mediterranean Region: Beyond drought effects. *Glob. Planet. Change* 148: 42–54. [doi: 10.1016/j.gloplacha.2016.11.012]

* *Surface albedo is the measure of the diffuse reflection of solar radiation out of the total solar radiation and measured in a scale of 0 (black body that absorbs all incident radiation) to 1, corresponding to a body that reflects all incident radiation.*

[186] Benas, N, and Chrysoulakis, N. (2015) - Estimation of the Land Surface Albedo Changes in the Broader Mediterranean Area, Based on 12 Years of Satellite Observations. Remote Sens. 7: 16150-16163. [doi:10.3390/rs71215816]

[187] Rotenberg, E., Yakir, D. (2010) – Contribution of semi-arid forests to the climate system. *Science*, 327: 451-454 [doi: 10.1126/science.1179998]

[188] Godinho, S., Guiomar, N., Rui Machado, R., et al. (2016) - Assessment of environment, land management, and spatial variables on recent changes in montado land cover in southern Portugal. *Agroforest Syst.* 90:177–192. [doi: 10.1007/s10457-014-9757-7]

[189] Sanz-Sanchez, M.-J. et al., (2017) - *Sustainable Land Management Contribution to Successful Land-based Climate Change Adaptation and Mitigation*. A Report of the Science-Policy Interface, United Nations Convention to Combat Desertification (UNCCD), Bonn, Germany, 170 pp.

[190] Giannakopoulou, Evangelia-Maria, Toumi, R. (2012) - Impacts of the Nile Delta land-use on the local climate. Atmospheric Science Letters 13(3): 208-215

[191] Carrer, D., Pique, G., Ferlicoq, M., Ceamanos, X. and Ceschia, E. (2018) - What is the potential of cropland albedo management in the fight against global warming? A case study based on the use of cover crops. *Environ. Res. Lett.*, 13, 44030 [doi:10.1088/1748-9326/aab650]

[192] Salvati, A., Monti, P., Roura, H.C., Cecere, C. (2019) - Climatic performance of urban textures: Analysis tools for a Mediterranean urban context. Energy and Buildings 185: 162-179. [https://doi.org/10.1016/j.enbuild.2018.12.024]

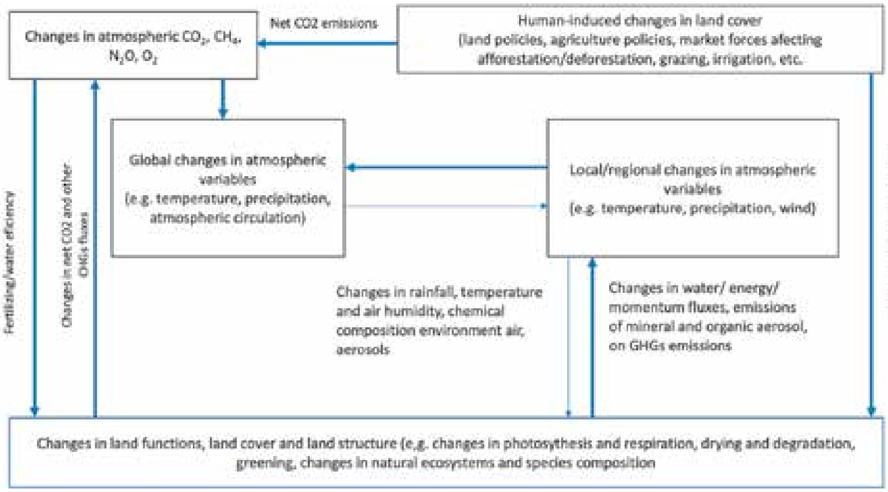


Fig. 27 – Interrelationships between climate change drivers and land cover and functions
Adapted from: Climate Change and Land Use[193]

Variations in temperature and precipitation regimes due to climate change affect the suitability of many areas of land for agriculture. Recent information and data show that observed climate change has already affected crop suitability in many regions of the world, including Europe, especially for Mediterranean crops (olive, sunflower, cereals, and grapevine). In some northern European countries, the projected longer growing season and the extension of frost-free areas are expected to produce positive effects, allowing the cultivation of new crops. Olive trees, for instance, may be cultivated in northern and central Italy, in new areas of France, and the north of the Iberia Peninsula.

Changes in land use and irrigation practices increase evapotranspiration and have a net cooling effect in some areas of the Mediterranean region (Zampieri and Lionello, 2011; Thiery [194]et al., 2017), provided the soil is correctly managed.

In southwestern and southern Mediterranean regions, the effects of higher temperatures will likely be more significant than in temperate zones. Shifting rainfall patterns may benefit certain areas, but greater variability in precipitation (more frequent droughts) poses a risk to 70 per cent of global rain-fed agriculture. Data has shown that wheat crop yield growth has slowed as the growing season changes (Schlenker[195] and Lobell, 2010; Lobell[196] and Gourdji, 2012). Increased concentrations of CO_2 in the atmosphere may benefit crop yields in certain regions through greater CO2 fertilization (McGrath[197] and Lobell, 2013), while warmer temperatures could bring yield gains in the high-latitude regions (IPCC 2014). Despite the generally reduced frost length,

---

[193] Climate Change and Land Use - An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems (2020).

[194] Thiery, W. et al., 2017: Present-day irrigation mitigate s heat extremes. *J. Geophys. Res.*, 122, 1403 – 1422 [doi: 10.1002/2016JD025740].

[195] Schlenker, W., and Lobell, D.B. (2010) - Robust negative impacts of climate change on African agriculture. *Environ. Res. Lett.*,5, 14010, [doi:10.1088/1748- 9326/5/1/014010]

[196] Lobell D. B. and Gourdji S. M. (2012) - The influence of climate change on global crop productivity *Plant Physiol.* 160: 1686–97

[197] McGrath, J.M., and Lobell, D.B. (2013) – Regional disparities in the CO_2 fertilization effect and implications for crop yields. *Environ. Res. Lett.* 8(1): 1-9.

late spring frosts may increase the risk of damage due to warming-induced precocious vegetation growth and flowering (Meir[198] at al., 2018; Primack[199] and Gallimat, 2016). In turn, projected warmer minimum temperatures will reduce the number of winter chill units required by temperate fruits and nuts. In those areas affected by the increased rainfall variability in water-limited regions and already affected by more extended drought events, crop yields are likely negatively impacted (EEA[200], 2019).

Global yields are expected to decline as average temperatures and troposphere ozone concentrations increase (Schlenker[201] and Roberts, 2009). Higher temperatures have led to increased distribution of certain weeds and pests (Pautasso[202] et al., 2012) and have exacerbated existing stresses during specific growing periods (Gourdji[203], Sibley and Lobell, 2013). On the other hand, climate-smart agricultural practices such as minimum tillage and energy-efficient crops and practices present an opportunity to increase the atmospheric carbon sink in soils and contribute to climate change mitigation. Likewise, efforts to reduce deforestation and forest degradation, conserve and increase forest carbon stocks, and sustainably manage forests globally can significantly reduce greenhouse gas (GHG) emissions and increase carbon sequestration in the living biomass and forest products.

5.7 - The problem of increasing land aridity

History shows that once civilizations prospered by thriving on good soils, they collapsed alongside their soil degradation. Even during the twenty-first century, a good soil is the engine of economic development and essential to present and future food security. Yet, human-induced and natural perturbations threaten the quality of soil resources. Soil quality is degraded by land misuse and soil mismanagement. The estimates of national costs of soil erosion are still few, but some studies, mainly in the developing world, e.g. Indonesia and Mali, show that its impact cost about 0.4% of GNP (Pearce[204], 1993).

Healthy and productive land resources – soil, water, and biodiversity – are the foundation of societies and economies. Roughly USD 44 trillion of economic output (more than half of global GDP) is moderately or highly reliant on natural capital (Folke[205] et al., 2021). However, in recent decades, land resources have been subject to persistent degradation (defined as the loss of land

---

[198] Meier, M., Fuhrer, J. and Holzkämper, A. (2018) - Changing risk of spring frost damage in grapevines due to climate change? A case study in the Swiss Rhone Valley. *Int. J. Biometeorol.*, 62, 991–1002, [doi:10.1007/s00484-018-1501-y]

[199] Primack, R., Gallimat, A. S. (2016) – Spring budburst in a changing climate. *American Scientist* 104 (2): 102-119 [doi: 10.1511/2016.119.102]

[200] EEA (2019) – Climate Change adaptation in the agriculture sector in Europe. European Environment Agency, Luxemburg. Publication Office of the European Union, 109 pp.

[201] Schlenker, W., Roberts, M.J. (2009) – Nonlinear temperature effects indicate severe damages to US crop yields under climate change. *PNAS*, 106 (37): 15594-15598 [www.pnas.org/cgi/doi/10.1073/ pnas.0906865106]

[202] Pautasso, M., Döring, T.F., Garbelotto, M., Pellis, L., Jeger, M.J. (2012) – Impacts of climate change on plant diseases – opinions. *Eur. J. Plant Pathol.* (Published online) [doi: DOI 10.1007/s10658-012-9936-1]

[203] Gourdji, S.M., Sibley, A.M. and Lobell, D.B. (2013) - Global crop exposure to critical high temperatures in the reproductive period: historical trends and future projections. Environ. Res. Lett. 8 (2013) 024041 (10pp) [doi:10.1088/1748-9326/8/2/024041]

[204] Pearce, David (1993) – Sustainable Development and Developing Country Economies, pp 71-105, in: Sustainable Environmental Economics and Management. Principles and Practice (ed.) R. Kerry Turner, Blhaven Press, 389 pp.

[205] Rockström, J., Beringer, T., Hole, D., Griscom, B., Mascia, M.B., Folke, C. and Creutzig, F. (2021) - Opinion: We need biosphere stewardship that protects carbon sinks and builds resilience. *Proceedings of the National Academy of Sciences*, 118(38). [https://doi.org/10.1073/pnas.2115218118]

productivity through various processes such as reduced biological diversity and activity, acidification, salinization, soil erosion due to wind and water, loss of soil structure, soil nutrient mining and pollution) and loss due to global patterns of human domination (UNCCD[206], 2017).

In addition to the gaps in knowledge, mention should be made of those resulting from the neglect of those relating to soil management techniques, whose importance has often been undervalued. Globally, soil is degrading, and fertility is declining, with an estimated 24 billion tonnes of fertile soil lost yearly due to extensive agriculture and improper use of resources, leading to increased pressure on existing farmlands (UNCCD[207]). During COP27 (2022), sessions stressed that over one-third of the Earth's surface is degraded, including half of all agricultural soil, the only source of many nutrients in our food. Even so, those benefits erode the planet since about 24 billion tons of fertile topsoil is lost yearly due to unsustainable land and soil management practices, resulting in degradation, erosion, salinization, compaction, acidification, and chemical pollution accumulation. It is estimated that poor soil management, pollution, intensive agriculture, disorderly urbanization, and severe erosion due to climate change have made 60 - 70% of European soils unhealthy (Soil Mission, EU Horizon Europe Programme).

Most countries and communities now recognize the urgent need to transform land governance through the restoration of degraded land and soil, considered the most fertile ground to take immediate and concerted action. Land and ecosystem restoration will help slow global warming, reduce the risk, scale, frequency, and intensity of disasters (e.g., pandemics, drought, floods), and facilitate the recovery of critical biodiversity habitat and ecological connectivity, to avoid extinctions and restore the unimpeded movement of species and the flow of natural processes that sustain life on Earth.

Ecosystem restoration is needed in the right places and at suitable scales to manage interconnected global emergencies better. Responsible governance and land use planning will protect healthy and productive land and recuperate biodiverse, carbon-rich ecosystems to avoid dangerous tipping points.

Drylands are characterized by low levels of precipitation, which do not compensate for the evaporative demands imposed by high temperatures and solar radiation (Reynolds[208] et al., 2007. Dryland ecosystems generally have low productivity, often exacerbated by erratic rainfall, resulting in long periods during which soil moisture depletion prevails without restoration. Low productivity generates low plant biomass, producing only small amounts of litter, reflected in low levels of organic matter incorporation in the soil.

About a quarter of the Earth’s ice-free land area is subject to human-induced degradation. Soil erosion from no-tillage agriculture fields is estimated to be 10 to 20 times higher than the soil formation rate. This value could reach 100 times under conventional tillage and cultivated slopes. Climate change exacerbates soil degradation and erosion on the topsoil and reduces its productivity, leading to an increase in aridity. Over the period 1961-2013, the annual drylands area in drought increased on average by slightly more than 1% per year. According to Burrel[209] et al. (2020) anthropogenic climate change has driven over 5 million km2 of drylands towards

---

[206] UNCCD (2017) - The Global Land Outlook, first edition, United Nations Convention to Combat Desertification, Bonn. [https://knowledge.unccd.int/glo/GLO_first_edition]

[207] UNCCD (2011) - Land and soil in the context of a green economy for sustainable development, food security and poverty eradication. [https://catalogue.unccd.int/850_Rio_6_pages_english.pdf].

[208] Reynolds, J.F., Smith, D.M.S., Lambin, E.F., Turner, B.L., Mortimore, M. et al. (2007) - Global Desertification: Building a Science for Dryland Development. *Science* 316: 847–851. [doi: 10.1126/science.1131634]

[209] Burrel, A. L., Evans, J.P. and De Kauwe, M.G. (2020) – *Nature Communications 11*, Article number 3853.

desertification. The human cost of this reduction in the productive potential of the affected areas can be translated by saying that in 2015, around 380-620 million people lived in regions experiencing desertification (IPCC, 2020) and suffered from high food insecurity.

For the sake of clarification, dryland and desertification are distinct categories. Drylands comprise land regions with a dry climate, limited water, and sparse vegetation. They include deserts, grasslands, shrublands and savannah woodlands that currently cover around 40% of the planet´s land surface. There is no single metric to identify drylands, and consequently, combining more than one measurement under the name of aridity index* (AI) is often used despite increasing recognition of its insufficient qualitative projections of various components of the terrestrial water cycle because it does not capture the relationship between climate change and land surface processes. Berg[210] and McColl (2021) use an alternative index of dryland based directly on relevant ecohydrological variables and compare projections of both indices in Coupled Models Intercomparison Project Phase 5 climate models and Dynamic Global Vegetation Models. Results showed the aridity index overestimates simulated ecohydrological index changes, reflecting that the aridity index does not capture trends in ecosystem stress and ignores physiological adaptation and biogeographical changes. In particular, it neglects the increased efficiency of ecosystem water use expected to follow the rise in atmospheric CO2 concentrations.

Desertification is understood as the degradation of land in arid, semi-arid and dry sub-humid zones as a result of complex interactions within coupled social-ecological systems, including climatic changes and anthropogenic activities [Article 1 of the text of the UN Conference for the Environment and Development (Rio, 1992)]. The "arid, semi-arid and dry sub-humid zones" are those that, except for the polar and subpolar zones, correspond to the areas of the Earth's surface in which the ratio between annual precipitation and potential evapotranspiration is between 0.05 and 0.65. More specifically, values of AI distinguish five classes: hyper-arid [AI<0.05], arid [0.05<AI<0.20], semi-arid [0,21<AI<0.50], dry sub-humid [0.51<AI<0.65] and sub-humid and humid > 0.65.

So, the relative contributions of climatic, anthropogenic and other drivers of desertification vary depending on specific socio-economic and ecological contexts. The high natural climate variability in dryland regions is a major cause of vegetation changes but does not necessarily imply degradation. Drought per se is not degradation, as the land productivity may return entirely once the drought ends (Kassas[211], 1995).

In the past decades, the scientific communities' understanding of the critical factors required for adequate land degradation assessment and monitoring has shifted. In that sense, the evaluation of land degradation changed from a mere biophysical perception to a more holistic approach, where human-induced or climate-driven underlying forces, as well as spatial and

* The aridity index was developed by Thornthwait, C.E. (1941) in Atlas of Climate Types in the United States (Miscell. Publ. No 421, U.S. Department of Agriculture, Forest Service was later used to prepare the Map of the World Distribution of Arid Regions, organised by UNESCO due to the International Hydrological Program, initiated in 1952. According to this definition, the degree of aridity of a region depends on the amount of water coming from precipitation (P) and the maximum possible loss of water through evaporation and transpiration (ETP) or Evapotranspiration Potential. Thornthwaite's formula, as the aridity index is known, was later adjusted by Penman, H.L. (1953) (The Physical Bases of Irrigation Control, in: *Report 13th Int. Hort. Congr.*, 2: 913-924, Royal Horticultural Society, London), to develop the classification that is accepted today.

[210] Berg, A. & McColl, K.A. (2021) – No projected global drylands expansion under greenhouse warming. *Nature Climate Change* 11: 331-337

[211] Kassas, M. (1995) - Desertification: A general review. *J. Arid Environ.*, 30: 115-128, [doi:10.1016/S0140-1963(05)80063-1]

temporal scale issues, have been recognised as factors that should be considered to understand and identify land degradation processes (Vogt[212] et al., 2011).

At this stage, the scientific community agrees that desertification's global extent and severity are still a relatively crude approximation with considerable uncertainties. Different indicator sets and approaches have been developed to monitor and assess desertification on national and global scales (Bestelmeyer[213] et al., 2013). Many indicators of desertification only include a single factor or characteristic of desertification, such as the patch size distribution of vegetation (Kéfi[214] et al., 2010), Normalized Difference Vegetation Index (NDVI) (Piao[215] et al., 2005), drought-tolerant plant species, grass cover (Bestelmeyer et al. 2013), land productivity dynamics (Baskan[216] et al. 2017), ecosystem net primary productivity (Zhou[217] et al. 2015) or Environmentally Sensitive Land Area Index (Symeonakis[218] et al., 2016).

In addition, some synthetic indicators of desertification have also been used to assess desertification extent and desertification processes, such as climate, land use, soil, and socio-economic parameters (Dharumarajan[219] et al. 2018), or changes in climate, land use, vegetation cover, soil properties and population as the desertification vulnerability index (Salvati[220] et al., 2009). However, current data availability and methodological challenges do not allow for accurate and comprehensive global mapping of desertification, including the Mediterranean basin (Cherlet[221] et al., 2018).

Despite the incertitude around assessing land degradation processes, including their causes and consequences on ecosystem functioning, and identifying affected areas and regions at risk, its understanding is a prerequisite to developing coherent strategies to mitigate and avoid land degradation. Accordingly, over the past decades, many national and international research initiatives reviewed the status of land degradation sciences, identifying gaps and developing strategies to assess and monitor land degradation and desertification.

---

[212] Vogt, J.V., Safriel, U., Von Maltitz, Sokona, Y., Zougmore, R., Bastin, G., and J. Hill, J. (2011) - Monitoring and assessment of land degradation and desertification: Towards new conceptual and integrated approaches. *Land Degradation & Development* [doi: 10.1002/ldr.1075]

[213] Bestelmeyer, B.T., Duniway, M.C., James, D.K., Burkett, L.M. and Havstad, K.M. (2013) - A test of critical thresholds and their indicators in a desertification-prone ecosystem: More resilience than we thought. Ecol. Lett., 16: 339345, [doi:10.1111/ele.12045]

[214] Kéfi, S., Alados, C.L., Chaves, R.C.G., Pueyo, Y., and Rietckerk, M. (2010) – Is the patch size distribution of vegetation a suitable indicator of desertification processes? Comment. Ecology, 91: 3739-3742, [doi:10.1890/09-1915.1]

[215] Piao, S., Fang, J., Liu, H., and B. Zhu, B. (2005) - NDVI-indicated decline in desertification in China in the past two decades. *Geophys. Res. Lett.*, 32, L06402, [doi:10.1029/2004GL021764]

[216] Baskan, O., Dengiz, O., and İ.T. Demirag, I.T. (2017) - The land productivity dynamics trend as a tool for land degradation assessment in a Dryland ecosystem. *Environ. Monit. Assess.*, 189: 212, [doi:10.1007/s10661-017-5909-3]

[217] Zhou, W., Gang, C., Zhou, F., Li, J., Dong, X., and Zhao, C. (2015) – Quantitative assessment of the individual contribution of climate and human factors to desertification in Northwest China using net primary productivity as an indicator. *Ecol. Indic*, 48: 560-569, [doi: 10.1016/J.ECOLIND.2014.08.043]

[218] Symeonakis, E., Karathanasis, N., Koukoulas, S. and Panagopoulos (2016) – Monitoring sensitivity to land degradation and desertification with the environmentally sensitive area index: The case of Lesvos Island. *L. Degrad. Dev.*, 27: 1562-1573, [doi:10.1002/ldr.2285

[219] Dharumarajan, S., Bishop, T.F.A., Hegde, R. and Ding, S.K. (2018) – Desertification vulnerability index – An effective approach to assess desertification processes: A case study in Anantapur District, Andhra Pradesh, India. L. Degrad. Dev, 29: 150-161, [doi:10.1002/Idr.2850]

[220] Salvati, L., Ziti, M., Ceccarelli, T. and Perini, L. (2009) – Developing a synthetic indexo f Land vulnerability to drought and desertification. *Geogr. Res.*, 47: 280-291.

[221] Cherlet, M. Hutchinson, C., Reynolds, J., Hill, J., Sommer, S., von Maltitz, G. (eds.), (2018) - *World Atlas of Desertification*. Publication Office of the European Union, Luxembourg, 248 pp.

The term "water shortage" should be understood as the characteristic of many environments linked to various natural and anthropogenic causes (Table 6). Aridity and drought are the natural xeric regimes, being the first permanent and the second temporary, although they can be long-lasting and are characteristics of climate oscillation.

Table 6 - Water scarcity regimes

Scarcity	Natural	Anthropogenically induced
Permanent	Aridity Low to very low average annual precipitation and great spatial and temporal variability of precipitation	Desertification Imbalance of water availability due to overexploitation of groundwater and/or surface water, combined with land degradation, erosion and inadequate land use, low infiltration, more frequent rapid floods and loss of riparian ecosystems
Transitory	Precipitation persistently below average, occurring with random frequency, duration, and severity, and which is difficult or even impossible to predict	Imbalance in water availability including over-exploitation of aquifers, reduced reservoir capacity, inadequate land use, degradation of water quality and reduced carrying capacity of ecosystems

Desertification and water shortages are caused by the misuse and abuse of natural resources, being the first permanent. It affects other natural resources long-term and is consequently difficult to eradicate. In contrast, the second is temporary and unrelated to climatic variations. There is general agreement that the primary cause of desertification is the removal of vegetation, which causes soil degradation with a consequent reduction of nutrients from the ground, making the land infertile and unusable for farming. Vegetal removal is mainly due to human activities but can also be associated with climate change. Desertification from human-induced land degradation can be accelerated under climate change, mainly due to extreme weather events, such as severe droughts. The main desertification drives in Europe are related to contamination, salinisation, soil compaction and loss of soil biodiversity (EEA[222], 2019).

Desertification exacerbates climate change through several mechanisms, such as changes in vegetation cover, sand and dust aerosols and greenhouse gas fluxes. The extent of areas where dryness (rather than temperature) controls CO_2 exchange has increased by 6% between 1948 and 2012. It is projected to increase by at least another 8% by 2050 if the expansion continues at the same rate (Mirzabae[223] et al., 2019). In these areas, net carbon uptake is about 27% lower than in

222 EEA (2019) – Climate change adaptation in the agriculture sector in Europe. European Environmental Agency, Copenhagen, 108 pp.

223 Mirzabaev, A., Wu, J., Evans, J., García-Oliva, F., Hussein, I.A.G., Iqbal, M.H., Kimutai, J., Knowles, T., et al. (2019) – Desertification: pp. 249-343. In: Climate Change and Land: an IPCC special report on climate change, desertification,

other areas. Desertification also tends to increase albedo, decreasing the energy available at the surface and associated surface temperatures and producing negative feedback on climate change. Desertification changes the absorption and release of associated greenhouse gases (GHGs) through their effect on vegetation and soils. Vegetation loss and drying of surface cover due to desertification increase the frequency of dust storms.

At the world level, more intense and more prolonged droughts have been observed since the 1970s, translated by the fact that the fraction of land surface area experiencing drought conditions has risen from 10 % to 15 % in the early 1970s to more than 30 % by early 2000 (Dai[224] et al., 2004). According to IPCC AR4, it is more likely than not that there is a human contribution to this trend. Decreased land precipitation and increased temperatures, which enhance evapotranspiration and reduce soil moisture, contribute to more regions experiencing droughts.

For the drylands, namely the land area surrounding the Mediterranean, it is not the effects of increased temperatures per se that are of significant concern but rather the changes in precipitation, storm events, snowfall and snowmelt, evapotranspiration, runoff and soil moisture reduction and the associated manifestations of drought (Thomas[225], 2008). Global analysis has shown that abrupt changes in rainfall are more likely to occur in arid and semi-arid regions. This susceptibility is possibly linked to strong positive feedback between vegetation and climate interactions.

Records of soil moisture indicate that higher temperatures and increased atmospheric records of soil moisture suggest that higher temperatures and increased atmospheric demand have strongly driven Mediterranean aridity. Multiple lines of evidence suggest that anthropogenic forcings are causing increased aridity and drought severity in the Mediterranean region. The Mediterranean domain has undergone an overall increase in arid areas from 64% to 78% at the expense of the more humid aridity classes (Daliakoupoulos[226] et al., 2017). Although Mediterranean basin lands experienced 10 of the 12 driest winters since 1902 in just the last 20 years (Hoerling[227] et al., 2012), anthropogenic greenhouse gas and aerosol forcing were identified as the key driving factors for this increased drying. An increasing trend toward agricultural and ecological droughts has been attributed to human-induced climate change in the Mediterranean (medium confidence). The model-based assessment shows a human fingerprint on increased hydrological drought related to rising temperature and atmospheric demand and frequency and intensity of recent drought events with medium confidence. There is moderate confidence that changes in land use and terrestrial water management contribute to trends in hydrological drought. However, the external signal explains only half of the drying magnitude (IPCC[228], 21).

---

land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.O. Pörtner, D.C. Roberts, et al. (eds).

[224] Dai, A, Trenberth, K.E., Qian, T. (2004) - A global set of Palmer Drought Severity Index for 1870 to 2002: relationship with soil moisture and effects of surface warming. *J Hydrometeorol.* 5: 1117–1130

[225] Thomas, R.J. (2008) - Opportunities to reduce vulnerability of dryland farmers in Central and West Asia and North Africa to climate change. *Agric Ecosyst Environ* 126: 36–45

[226] Daliakopoulos IN, Panagea IS, Tsanis IK, Grillakis MG, Koutroulis AG et al. 2017 Yield Response of Mediterranean Rangelands under a Changing Climate. *L. Degrad. Dev.* 28, 1962–1972. [doi: 10.1002/ldr.2717]

[227] Hoerling M., Eischeid J., Perlwitz J., Quan X, Zhang T, Philip, P. (2012) - On the increased frequency of Mediterranean drought. *J Climate* 25: 2146–2161.

[228] IPCC (2021) - Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [Masson-Delmotte, V., P. Zhai, A., Pirani, S. L., Connors, C. Péan, S. Berger, N. Caud, Y. Chen, L. Goldfarb, M. I. Gomis, M. Huang, K. Leitzell, E. Lonnoy, J.B.R. , Matthews, T. K., Maycock, T., Waterfield, O., Yelekçi, R. Yu and B. Zhou (eds.)]. Cambridge University Press. 3949 pp.

Furthermore, sea surface temperature (SST) forcing during 1902–2010 likely played an essential role in the observed drying of the Mediterranean.

The frequency and intensity of extreme weather events have increased due to global warming, and it is foreseeable that it will continue to grow under medium and high emission scenarios (AR6[229] Report, 2021). Although with regional intensity differences, climate change, translated into increased temperatures and decreased rainfall, duration, and frequency, affects water availability in the soil and creates additional water stresses on the ground, exacerbating living conditions, the food systems and human health, which are projected to happen, with high probability in Mediterranean basin countries. Arid lands already cover 33.8% of the northern Mediterranean countries: approximately 69% of Spain, 66% of Cyprus and between 16% and 62% of Greece, Portugal, Italy, and France (Zdruli[230], 2011).

The European Environment Agency (EEA) indicated that 14 million hectares, or 8% of the territory of the European Union (mainly in Bulgaria, Cyprus, Greece, Italy, Romania, Spain, and Portugal), were very prone to degradation and high sensitivity to desertification (European Court of Auditors 2018). This number increases to 40 Mha (23% of EU territory) if "moderately" sensitive areas are included (Prăvălie[231] et al., 2017).

According to EEA[232] (2015) assessment report, Europe is increasingly affected by increased aridity, leading to significant land use consequences, particularly in Portugal, Spain, Italy, Greece, Malta, Cyprus, Bulgaria, and Romania. Using the Universal Soil Loss Equation, it has been estimated that soil erosion can reach 300 t $ha^{-1}year^{-1}$ (equivalent to a net loss of 18 mm $year^{-1}$) in Spain (López-Bermúdez[233] 1990), which we assume will be of the same order of magnitude in Portugal.

Desertification in MB is driven by imprudent irrigation developments and the encroachment of pasture cultivation (Safriel[234], 2009) caused by population growth, agricultural policies, extensive land abandonment, especially after 1960 (Stellmes[235] et al., 2015) and markets. The abandonment of vast used agriculture areas in depopulated regions, the discontinuation of traditional forms of agro-silvo-pastural land use (e.g. montados/dehesas) in some regions and an increase in livestock grazing, are clear anthropogenic drivers of increased aridity in the Mediterranean domain.

---

229 AR6 Report (2021) - Climate Change and Land (Chapter 2, Land-Climate Interactions), pp 131-230. In: An IPCC Special Report on climate change, desertification, land degradation, sustainable land management, food security and greenhouse gas fluxes in terrestrial ecosystems. [access: www.ipcc.ch]

230 Zdruli, P. (2011) - Desertification in the Mediterranean Region. European Institute of the Mediterranean. Girona, pp. 250-255.

231 Prăvălie, R., Patriche, C. and Bandoc, G. (2017) – Quantification of land degradation sensitivity areas in southern and central south-eastern Europe. New results based on improving DISMED methodology with new climate data. Catena, 158: 309-320

232 EEA (2015) – in: Remote Sensing of Water Resources, Disasters, and Urban Studies. (ed) Presad S. Thenkabai, CRC Press, 1st ed, 707 pp.

233 López-Bermúdez, F. (1990) - Soil erosion by water on the desertification of a semi-arid Mediterranean fluvial basin: The Segura Basin. *Spain. Agric. Ecosyst. Environ*., 33, 129-145, [doi: 10.1016/01678809(90)90238-9].

234 Safriel, U. (2009) – Deserts and desertification: Challenges but also opportunities. L. Degrad. Dev. **20**: 353–366, [doi: 10.1002/ldr.935].

235 Stellmes, M., Sonnenschein, R., Röder, A., Udelhoven, T., Sommer, S. and Joachim Hill, J. (2015) – Land degradation assessment and monitoring of drylands, Chap. 17. In: *Remote Sensing of Water Resources, Disasters and Urban Sudies* (ed) P.D. Thenkabail. CRC Press. 707 pp.

As far as Portugal is concerned, it suffices to say that in its southern region, already heavily affected by the increasing aridity, the "montado", the agro-silvo-pastoral system rare in Europe and the world disappears at the rate of about 5 thousand ha per year, substituted by super intensive olive oil and almond orchards.

5.7.1 – Aridity trends in the Portuguese mainland

Given the importance of irrigation in containing vagaries of rainfall facing Portuguese agriculture, the Aridity Index (AI) analysis seems to be a good instrument for predicting how much Portuguese agriculture depends on water availability.

Drought phenomena correspond to situations in which a transient anomaly occurs from the normal precipitation conditions for a given region in a certain period, which may result in an extreme phenomenon. Due to this rainfall deficit, there is an evolution of the complexity and severity of impacts verified at different levels, according to Figure 28.

It is consensual to consider that water scarcity is a character with a natural and an anthropogenic component, the first being permanent and the second temporary, with periods that are more or less long depending on the characteristics of the climate. Human action strongly influences desertification processes, mainly due to the misuse of natural resources.

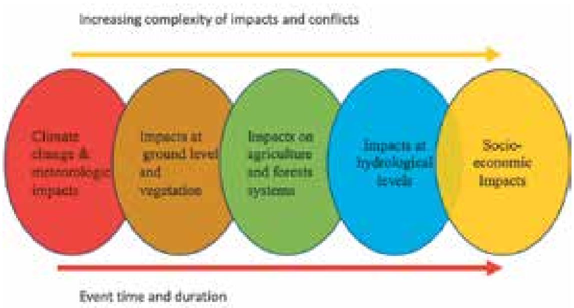


Fig. 28 – Levels impacted by extreme events of droughts and climate changes
Adapt. from: Vivas[236] & Maia, 2007

The results obtained by spectral analysis of the annual precipitation time series for 22 locations in southern Portugal (the most sensitive to drought) show that the periods of the most important periodic components tend to cluster in the range of 10 to 15 years (Pereira[237], 2010). Although the analysis period is not sufficiently long for long-term predictions, the results are consistent with the periodicity of severe droughts and not with the tendency for the increase of drought or their intensity. Management plans should look at the reasonable probability of severe droughts in 10 to 15 years after another drought of similar severity. However, in the last decade (Pires et al., 2018) has shown that the period between droughts seems to be decreasing.

---

[236] Vivas, E, and Maia, R. (2007) – Caracterização das principais situações de seca históricas em Portugal continental – a importância da utilização de indicadores. 2as Jornadas de Hidráulica e Ambiente. FEUP, 51- 61

[237] Pereira, L.S. (2010) – Introdução à gestão do risco em secas. In: Pereira, Mexia e Pires (eds)

In the southern region, the results by Pereira (2010) show that the occurrence and severity of droughts behave according to a cyclical variability, as subperiods with few severe/extreme droughts are followed and preceded by higher frequency subperiods.

These cycles, in which the subperiod's duration varies from 26-30 years, may be related to natural long-term variability. For other locations, especially those in the North, there is no evidence of cyclical behaviour or trends towards the progressive worsening of drought over the last century. However, if we compare the last period of 27 years with the antecedent of 24, there is generally a significant increase in the occurrence and severity of droughts (Moreira[238], Mexia and Pereira, 2010).

The cause-effect relationships between drought and desertification are recognised. Mainland Portugal is no exception to this rule, as the increase in dryness and susceptibility to aridity, defined by the Aridity Index (AI), has been translated into an increase in the last 50 years. This finding converges with the latest IPCC scenarios on climate change, which indicate an increase in aridity in the Mediterranean basin, particularly in the Iberian Peninsula. In particular, the comparative analysis of AI data for 1960-1990, 1970 - 2000 and 2000 - 2010 shows that the susceptibility area to desertification has expanded in Portugal. In spatial terms, the susceptibility to desertification, which affected 36% of the national territory in the 60/90 series, rose to 58% in the 1980/2010.

In terms of the territory, despite the increase in aridity, its spatial distribution is not uniform. In fact, there were changes in opposite directions: i) regression of aridity in almost the entire border area (mainly in the tributary valleys of the Douro); ii) an increase in aridity in the central and southern coastal areas and iii) an increase in aridity in the NW areas, one of the rainiest areas in Europe.

Changes in the spatial distribution of the different classes of aridity (Table 7) translate into losses in biological productivity of rainfed or irrigated agricultural lands, natural or sown pastures, forests, or areas of cultivation under agro-silvo-pastoral regime due to the use of systems and processes that favour soil erosion by wind or water, deterioration of physical and chemical properties of soils and destruction of vegetation cover for prolonged periods.

The regional modelling studies confirm the outcomes of Global Climate Models that point to a decrease in soil moisture in the Mediterranean, southwest USA, and southern African regions, in line with alterations in the Hadley circulation and higher surface temperatures. Since this surface drying will continue to the end of this century (high confidence) under RCP4.5 and RCP8.5 scenarios, it is worth looking for what this means regarding water availability in Portugal.

Evapotranspiration has a fundamental role in the water balance together with precipitation. The balance between the water received through rainfall, and that lost through evapotranspiration will result in water storage variation in the soil, which will condition the vegetative cycle of plants.

---

[238] Moreira, E., Mexia, J.T., and Pereira, L.S. (2010) – Sobre o possível agravamento da frequência e severidade das secas, pp 248-249. In: Pereira, Mexia and Pires (eds)

Table 7 – Evolution of areas of susceptibility to desertification in mainland Portugal in the last 50 years

Aridity classes	1960-1990 %	1970-2000 %	1980-2010 %	2000-2010 %
Semiarid	28	24	31	45
Dry sub-humid	8	29	28	18
Dry or Arid land areas	36	53	58	63
Sub-humid wet		9	10	9
Humid		37	33	29
Atlantic areas	64	46	42	37

Source: Proposta de Plano de Prevenção, Monitorização e Contingência para situações de seca [Proposal for a Prevention, Monitoring and Contingency Plan for drought situations] [https://www.dgadr.gov.pt/plno-de-prevencao-monitorizacao-e-contingencia-para.situacoes-de-seca], 160 pp.

Projections for these two variables towards the end of the 21st century (2091-2100 decade) (Fig. 29) point out, on the one hand, to a decrease of annual precipitation in mainland Portugal and, on the other, for an increase in evapotranspiration of +77mm and +184 mm for scenarios RPC 4.5 and RPC 8.5, respectively.

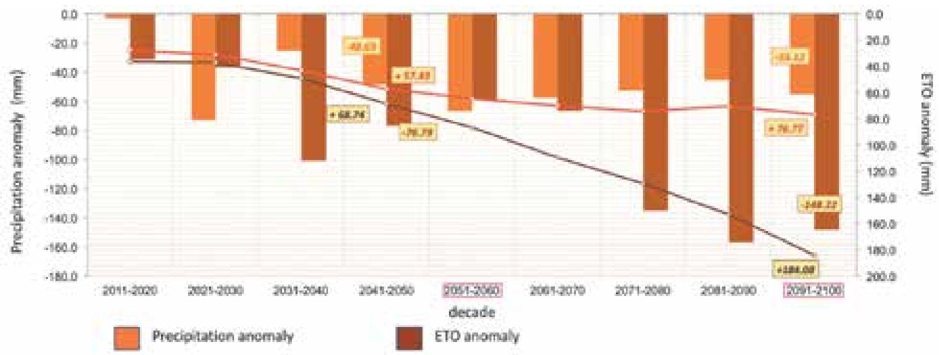


Fig. 29 - Scenario RCP4.5 and RCP8.5 of annual precipitation and evapotranspiration in mainland Portugal (difference concerning the 1971-2000 mean values) (Ensemble – www.portaldoclima.pt/pt/)

The current and foreseeable water resources in Portugal can generically be characterized by its irregular spatial distribution (greater abundance to the north and on the Atlantic side, greater scarcity south of the Tagus River and the continental slope), marked seasonality (rainfall is concentrated between the end of autumn and the beginning of spring) and interannual irregularity. So, quantifying the water balance and considering its repercussions on the agriculture sector is critical for prudent agriculture planning and water management.

Table 8 depicts the average natural runoff volumes for a normal year and dry year, with estimated average annual water availability for reservoirs (useful capacity) and aquifers (medium underground runoff in confined aquifers) of the Mainland's Hydrographic Regions.

Values show lower water availability and a more significant variance of natural runoff in the Tagus and South hydrographic basins.

The National Water Plan summarises the volumes of water used by the main sector (Table 9) for the Hydrographic Regions of the continent.

The DQA[239] reports evaluate each Hydrographic Region (RH) according to the existing and projected consumptive uses, which is the balance between needs and availability of water, surface, and underground (Table 10). For this purpose, they rely on the scarcity index WEI+ (Water Exploitation Index), which corresponds to the ratio of the annual average water demand and the average resources available in the long term. This index developed by the UN allows you to assess the average water stress in each hydrographic region.

Table 8 - Water availability in the hydrographic regions of mainland Portugal

Hydrographic regions	Hydrographic basins	Flow (hm^3)	Dams (hm^3)	Dams (% inflows)	Aquifers (hm^3)
RH1	• Minho • Lima	3275/2319	- 355	- 12	248
RH2	• Cávado • Ave • Leça	3607/2379	1142 - -	50 - -	303
RH3	• Douro	8010/4933	1300	7	1084
RH4	• Vouga • Mondego • Lis	6826/3813	88 361 -	4 11 -	1416
RH5	• Oeste • Tejo	6710/2411	- 2355	- 20	3499
RH 6	• Sado • Mira	1159/241	444 240	30 73	564
RH7	• Guadiana	1771/578	3244	72	406
RH 8	• Algarve	622/193	230	58	388
MAINLAND		31980/16767	9759	20	7908

Source: ANP/WWF[240] (2019)

The water balance presented does not show very relevant situations of water stress. However, the values given in the Tagus and West basins, and to the south of these, correspond to a level of moderate scarcity (> 20%), according to the classification of this index. In recent years, especially after 2018, the lack of rainfall has been critically felt mainly in the south. The balance situation is

[239] Diretiva Quadro da Água (2005) – Relatório Síntese sobre a Caracterização das Regiões Hidrográficas Prevista na Directiva-Quadro da Água. Instituto da Água, Ministério do Ambiente, do Ordenamento do Território e do Desenvolvimento Regional, 175 pp. [http://www.ambiente.pt/dqa/assets/ relatório_artigo_5_pt.pdf].

[240] ANP/WWF (2019) – Vulnerabilidade de Portugal à seca e escassez de água. Associação Natureza Portugal in association with the World Wild Fund for Nature. Relatório 2019, 32 pp.

marked by a manifest shortage, mainly in the eastern Algarve, which led the government in 2024 to enact water rationing measures for all sectors of economic activity.

Regarding the values of these water availability tables, they should be read with some reserve as: i) The quantification approach is made exclusively from the perspective of water as a mere productive factor for the different economic sectors, forgetting the crucial role it plays in the provision of ecosystem services such as, among others, those related to ecological flows; ii) The results do not reflect the significant seasonal and inter-annual variations in uses, namely due to the significant variability of demand; iii) The values in Tables 9 and 10 do not include the critical water transfers that can be observed in the national territory to meet the needs that are quantified in the receiving basins; iv) The values for calculating the scarcity index are based on estimates using indirect methods, and their validation requires data obtained through monitoring controlled and real processes and adjusting most existing water intakes (as planned but not yet implemented).

Table 9 - Water volumes captured by sector and Mainland River Basin in hm3 / year and percentage of total.

Economic sector	RH1	RH2	RH3	RH4	RH5	RH6	RH7	RH8	Total
Urban	26 (19%)	61 (14%)	161 (19%)	103 (14%)	394 (23%)	25 (5%)	72 (15%)	47 (22%)	889 (18%)
Industrial	8 (5%)	45 (11%)	7 (1%)	66 (9%)	67 (4%)	32 (6%)	1 (0%)	1 (0%)	227 (4%)
Agriculture & animal husbandry	105 (75%)	318 (75%)	684 (76%)	571 (76%)	1181 (69%)	432 (86%)	362 (78%)	149 (67%)	3802 (75%)
Golf	1 (1%)	2 (0%)	3 (0%)	2 (0%)	13 (1%)	0 (0%)	1 (0%)	15 (7%)	37 (1%)
Others	0 (0%)	0 (0%)	0 (0%)	8 (1%)	52 (3%)	15 (3%)	32 (7%)	9 (4%)	116 (2%)
Total	140	426	855	750	1707	504	468	221	5071

Source: Plano Nacional da Água [National Water Plan], 2012

Despite these limitations, the comparison of the volumes presented in tables 8, 9 and 10 allows us to identify conditions of structural scarcity whose tendency is to increase in the face of future scenarios of higher temperatures, reduced rainfall, increased frequency of droughts and extreme events, or plans for increasingly intensive agriculture on irrigated land, mainly in southern Portugal.

More importantly, as far as we have been able to research, existing data, based on balances of mean values, are of little use for the assessment of extreme situations because they do not provide us with the probabilities of the occurrence of surpluses or the achievement of drought thresholds that can occur in a specific sector, place, or time as they are hidden under any average index per basin.

As for the socio-economic impacts of the less recent events of the drought, the information found is very scarce and limited, except for the year 2004/2005. However, the data collected by Vivas and Maia (2007) gave a partial picture of the sectorial economic impacts of some years of drought, as summarized in Table 11.

Although compound drought-heatwave events remain poorly understood concerning the physical mechanisms behind them and their impacts on socio-ecosystem productivity, they are considered one of the worst climatic stressors for global sustainable development (Yin[241], et al., 2023). By combining satellite observations, field measurements, and reanalysis, the authors showed that terrestrial water storage and temperature are negatively coupled. Their limits on water availability are likely to play a more critical role in constraining the terrestrial carbon sink than temperature extremes.

Table 10 - WEI+ scarcity index for Portugal's hydrographic regions.

Hydrographic Region	Hydrographic basin	WEI+ (%)
RH1	• Minho	4
	• Lima	7
RH2	• Cávado	8
	• Ave	16
	• Leça	38
RH3	• Douro	11
RH4	• Vouga	18
	• Mondego	15
	• Lis	9
RH5	• Oeste	33
	• Tejo	22
RH6	• Sado	27
	• Mira	14
RH7	• Guadiana	22
RH8	• Algarve	32
Portuguese mainland		16

Source: ANP/WWF (2019)

Given that the projections predict that the frequencies of compound drought-heatwaves events will increase by tenfold globally under the higher emission scenarios, it will be important that the probabilities of occurrence of this type of compound events are adequately analysed in the context of the Alentejo given the already present situation of high aridity indicators and increased frequency of drought events.

The record of droughts' economic effects on agriculture and forest fires in Portugal is scarce, and scattered data are only available for 2005 and 2012. "*The dispersion of intervening entities, differences in procedures, and lack of standardization of action have impeded the assessment of droughts'*

[241] Yin, Jiabo, Gentine, P., Slater, L., Gu, L., Pokhret, Y., Hanasaki, N. Gua, S., Xiong, L. and Schenker, W. (2023) – Future socio-ecosystem productivity threatened by compound drought-heatwave events. *Nature Sustainability* vol 6: 259-272

socioeconomic impacts", as mentioned in the Prevention, Monitoring and Contingency Plan for Drought Situations. "*During the 2012 drought monitoring process, several gaps in the organized and effective response to drought situations in the country were detected*". As a result, several working groups were created, and specific competencies for each of them were defined. To convey and make this organized information available to potential users and interested parties, a "Drought Portal" was proposed, which was only formalized in June 2017 by Resolution of the Council of Ministers 80/2017.

5.8 - Soil erosion

With more than half of the world's agricultural land already seriously degraded, COP27 (2022) in the person of Leigh Winnowiecki, the co-leader of the Coalition of Action 4 Soil Health (CA4SH), launched a strong alert to policymakers and legislators regarding the need for urgent action and binding actions for its recovery. It is necessary not to forget that the soil is the absolute foundation of life on land, the basis of the world's food system, and the third-largest carbon sink.

There is ample consensus that healthy soil is critically important for climate change mitigation and adaptation, ecosystem restoration, and food and nutrition security. Soil management must consider minimising the risks to human and environmental health. Even so, those benefits are eroding as the planet is losing, each year, through erosion, 24 billion tons of fertile topsoil (TetraPack[242], 2023) due to unsustainable land and soil management practices that result in degradation, erosion, salinisation, compaction, acidification, and chemical pollution accumulation. Correct action could be needed through regenerative farming techniques, including growing trees and crops that meet the world's need to feed its growing population while removing carbon from the atmosphere and sequestering it in their land. It also emphasises the value of healthy soil as a nature-based solution that contributes to combating climate change since soil can sequester carbon. Healthy soil can also restore biodiversity, improve water resilience, increase nutritious crop yields, and enhance food security while building nature-positive food production systems.

Soil erosion, defined as the accelerated removal of topsoil from the land surface (FAO[243] and ITPS, 2015), is one of the most visible signs of soil degradation and has received the most attention when talking about soil conservation. It involves transporting and depositing soil particles by water or wind from their original place to another location. Factors influencing soil erosion, considered one of the leading causes of land degradation, are topography (slope steepness and length), soil erodibility (determined by soil properties such as texture, structure, moisture, organic carbon content, etc.), vegetation cover and management practices. When soil is left bare, the delicate carbon-nutrient-rich fractions are removed first, altering physical, chemical, and biological soil properties, such as soil albedo, temperature, evapotranspiration, water holding capacity and soil biodiversity at a variety of scales, which disrupt ecosystem functioning.

---

[242] TetraPak (2023) – How could global food systems better sustain our planet and its people by 2040? White paper series in collaboration with EY-Parthenon, 48 pp.

[243] FAO, ITPS (2015) - *Status of the World's Soil Resources - Main Report.* Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy

Table 11 - Assessment of the main sectoral impacts resulting from drought events (Values updated as of 2007)

Sector	Most affected river basins	Major impacts	Costs
Year 1980/81 e 82/83			
Agricultura	Douro, Mondego, Tejo, Sado, Guadiana, Algarve	• Most affected crops: chickpea and sunflower; • Very bad pastures until spring 1983; • Slaughter of farmed cows; • Moderate yield breaks in irrigated orchards, corn and bean	without estimate
Domestic supply	Guadiana, Algarve	• Supply wells to some villages were left without water; • Supply of populations by auto tank; construction of some emergency works	15 M€
Business activities	--	--	without estimate
Energy generation	Tejo	• Flow reduction in the Tagus	without estimate
Biomass and diversity	--	--	without estimate
Year1993			
Agriculture	Douro, Tejo, Sado Guadiana, Algarve	• Most affected crops: chickpea and sunflower; • Watering conditions for cattle severely affected;	without estimate
Domestic supply	Douro, Mondego, Rib. West, Tejo, Guadiana	• Supply problems in some municipalities; Decrease in water quality	12 M€
Business activities	--	--	without estimate
Energy generation		• Reduction of turbocharged volumes	without estimate
Biomass and diversity	--	--	without estimate
Years 2004/2006*			
Agriculture	Douro, Vouga, Mondego, Rib. West, Sado, Mira, Guadiana, Algarve	• Rainfed crops; Irrigated crops with restrictions; Affected yield of permanent crops including forest yields; • Watering conditions for cattle severely affected and increased imports of fodder	520 M€
Domestic supply	Douro, Mondego, Rib. West, Tagus, Guadiana	•Problems in the supply of some municipalities(supply restrictions, auto-tank delivery, new well drills; • Water quality reduction	12 M€
Business activities	--	--	518 M€
Energy generation			without estimate
Biomass and diversity			without estimate

Data source: Vivas & Maia (2007); * ANP/WWF (2019)

An assessment of the global severity of soil erosion in agriculture indicated that the global net median rate of soil formation (i.e., formation minus erosion) is about 0.004 mm yr^{-1} (about 0.05 t ha^{-1} yr^{-1}) compared with the median net rate of soil loss in agricultural fields, 1.52 mm yr^{-1} (about 18 t ha^{-1} yr^{-1}) in tilled fields and 0.065 mm yr^{-1} (about 0.8 t ha^{-1} yr^{-1}) in no-till fields (Montgomery[244] 2007). This means that the rate of soil erosion from agricultural fields is between 380 (conventional tilling) and 16 times (no-till) the natural rate of soil formation. These approximate figures are supported by a large meta-study including over 4000 sites around the world where the average soil loss from agricultural plots were about 21 t/ha/yr (García-Ruiz[245] et al. 2015). Climate change, mainly through the intensification of rainfall, will further, increase these rates unless land management is improved.

Environmental effects of soil erosion are i) soil productivity decrease; ii) soil infiltration rate decrease; iii) vegetation cover degradation; iv) flood risks increase; v) water quality decrease; vi) irregularity of river flow; vii) increased dam sedimentation.

Recent scientific insights (Reynolds[246] et al., 2007) place soil degradation, including erosion, in a broader perspective. From that perspective, soil erosion is a biophysical factor and a feedback component in complex socio-environment systems that disrupt essential ecosystem services and the human economic systems that rely on them Lal[247] and Stewart, 2011).

Quantifying the extent and intensity of soil erosion has proved a complex subject to high uncertainty. Erosion is site-and-scale-dependent with high temporal variability that requires creating standardized, long-term monitoring systems with nested scales to gather representative, reliable, and comparable data. So, reported erosion rates show high variability depending on the approach used (whether measured in plot or modelled), the monitored processes (sheet, erosion, gully) and the scale (plot, hillslope or catchment).

An extensive review of published erosion plot data estimated that the erosion rate between rill and inter-rill reached values of 1.3 t/ha/year for the Mediterranean area of Europe (Cerdan[248] et al., 2010). This accounts for 21.5% of total Pan-European soil losses. Measured erosion is strongly influenced by land use. A similar study confirms the critical role of land use as a determinant factor in erosion rates in the Mediterranean (Maetens[249], 2013) (Table 12). The mean annual rate for bare plots and plots where crops have been cultivated ranges from 1 to 20 t/ha/year, while plots with permanent cover have erosion rates lower than 1 t/ha/year.

The erosion rates are lower for bare and cultivated areas than in wetter parts of Europe. However, areas covered by semi-natural vegetation showed higher rates than in the rest of Europe (yet lower than 1 t/ha/year). These counterintuitive low soil erosion values obtained for some Mediterranean regions are explained by the large fraction of rock fragments on the topsoil

---

[244] Montgomery, D.R., Beguería, S., Nadal-Romero; E., González-Hidalgo, J.C., Lana-Renault, N., Sanjuán, Y. (2007) - Soil erosion and agricultural sustainability. *Proceedings of the National Academy of Sciences*, 104(33): 13268–13272 [doi: 10.1073/pnas.0611508104].

[245] García-Ruiz, J.M. et al. (2015) - A meta-analysis of soil erosion rates across the world. *Geomorphology*, 239: 160–173, [doi:10.1016/j. geomorph.2015.03.008].

[246] Reynolds, J.F., Sttaford; D.M., Lambin, E.F., Turner, B.L. et al. (2007) – Global desertification: Building a science for dryland development. *Science* 316 (5826): 847-851.

[247] Lal, R. and B.A. Stewart, B.A. (eds) (2011) - World Soil Resources and Food Security. CRC Press, 158 pp.

[248] Cerdan, O., Govers, G., Le Bissonnais, Y., Van Oost, K., Poesen, J., Saby, N., Gobin, A., et al. (2010) - Rates and spatial variations of soil erosion in Europe: a study based on erosion plot data. *Geomorphology, 122* (1-2): 167-177.

[249] Maetens, W. (2013) Effectiveness of land use and soil conservation techniques in reducing runoff and soil loss in Europe and the Mediterranean. KU Leuven Thesis/Dissertation.

and other significant erosion mechanisms such as gully erosion, landslides and riverbank erosion that are not well-represented at a plot scale.

Table 12 – Average erosion rates by land use in the Mediterranean region

Land use	Erosion rate measured at plot scale (t $ha^{-1}yr^{-1}$)	
	[1] Cerdan et al., 2010	[2] Maetens, 2013
Bare	9.05	9.1
Arable	0.84	2.9[1]
Forest	0.18	0.4
Grassland	0.32	0.6-0.8
Shrubs	0.54	0.6
Vineards	8.62	1.8
Orchards	1.67	11.6[2]

1 Data is mentioned for cropland (cereal, maize, sugar beet, sunflower)

2 This is referred to fruit tree crops (olive, almond, citrus)

Field measurements across the European Mediterranean region have shown variable erosion rates, revealing that it is particularly problematic for agricultural land (Ferreira[250] et al., 2018) and in wildfire-affected areas (Shakesby[251] et al., 2015), but also in urban areas. Gully erosion, the most severe form of erosion, is particularly common in Spain, Italy, and Greece (Verheijen[252] et al., 2009), leading to extreme erosion rates of up to 455 t ha^{-1} yr^{-1} (Poesen[253] et al., 2006). Topsoil loss reduces soil capacity to provide rooting space and water store, with an estimate 4% yield decline per 0.1 m of soil loss (FAO[254], 2015). This may have serious impacts in Mediterranean forest, where soils are thin and poor, particularly in mountainous areas (Shakesby[255] et al., 2015; Miranda[256] et al., 2018).

Although 2015 was declared the International Year of Soils, political mobilisation is still relatively weak on this issue. Yet, FAO[257] (2011) highlighted that 33% of land is moderately or severely degraded due to erosion, salinisation, compaction, acidification, and chemical pollution. The extent of soil degradation threatens the capacity of future generations to satisfy their dietary and energy needs. Estimates show that the existing land degradation and desertification rates,

---

[250] Ferreira, Carla S.S., Seifollahi-Aghmiuni, S., Destoumi, G., et al. (2018) – Soil Degradation in European Mediterranean region: Processes, status and consequences. Science of Total Environment, Vol 805, Jan, 150106

[251] Shakesby, R.A., Bento, C.P., Ferreira, C.S., Ferreira, A.J., Stoof, C.R., E. Urbanek, E., Walsh, R.P. (2015) - Impacts of prescribed fire on soil loss and soil quality: an assessment based on an experimentally burned catchment in Central Portugal. Catena, 128:278-293

[252] Verheijen, R.G.A., Jones, R.J.A., Rickson, R.J., Smith, C.J. (2009) – Tolerable versus actual soil erosion rates in Europe. *Earth Sci. Rev.*, 94 (1-4): 23-38.

[253] Posen, J., Vanwalleghem, T., De Vente, J., Knapen, A., Verstraten, G., Martinez Casasnova, J.A. (2006) – Gully erosion in Europe, 515-536. In: J. Boardman, J. Poesen (Eds.), *Soil Erosion in Europe*, Wiley and Sons, Chichester.

[254] FAO (2015) - World Fertilizer Trends and Outlook to 2018. Food Agriculture Organization, Rome, Italy.

[255] Shakesby, R.A., Bento, Celia, Ferreira Carla, Ferreira, A.D., Stoof, C., Urbanek, E., Walsh, R.P.D. (2015) – Impacts of prescribed fire on soil loss and soil quality. *Catena*, 128: 278-293. [www.elsevier.com/locate/catena]

[256] Miranda, E.D., Attorre, F., Azevedo, J., Belen, I., Alcalde, E.E., Freitas, H., Garavaglia, V.,Hódar, J.A., Iritas, O., Karaaslan, Y., et al. (2018) - Drivers of degradation and other threats 2-15, Chapter 1. In: State of Mediterranean Forests 2018. Food and Agriculture Organization of the United Nations, Rome and Plan Bleu, Marseille,

[257] FAO (2011) - *The State of the World's Land and Water Resources for Food and Agriculture: Managing Systems at Risk*. Rome and London, FAO-Earthscan.

including land take and soil sealing (due to urbanisation and infrastructure development), will continue. In 2020, another 8.3 million hectares of agricultural land was lost compared to 1960.

The consequences of land degradation are dire as the global agricultural land per capita would drop from 0.48 hectares in 1961 to 0.21 hectares, or less than half in 2020 (Zdruli[258], 2014).

The importance of this degradation in terms of food security is well illustrated if we consider that by 2050, the supply of food, animal feed and fibre will have to increase by 60% to feed a global population of between 8 and 11 billion people (Dorin[259] et al., 2010). The scope for expanding areas of arable land is limited since most available land is not suited to agricultural production.

Due to human-created pressures and global warming, some soils in Europe´s Mediterranean region are reaching what the researchers refer to as "*critical limits for their ability to provide ecosystem services,*" including, among others, farming and sequestration carbon capacity (Ferreira[260] et al., 2022). These gloomy scenarios that also affected south Mediterranean countries can potentially drive social unrest, accelerated waves of immigration towards the North Mediterranean (already occurring), and perhaps, in the longer term, increased unemployment, famine, and civil strife, including ethnic/religious reprisals.

Soils are the main terrestrial reservoir of organic carbon, nitrogen, and phosphorus. Thus, any disturbance, e.g., land use changes or soil erosion that alters soil integrity threatens planetary scale biogeochemical cycles that sustain the Earth's life-support systems (Williams[261] et al., 2016). Soil erosion impacts the residence time of these elements (carbon, nitrogen, phosphorus) in soils, as well as their flux rates, storage, and distribution of these elements (Chappel[262] et al., 2016; Smith[263] et al., 2015).

Soil erosion management includes conservation practices (e.g., the use of minimum tillage or zero tillage, crop rotations and cover crops, rational grazing systems), engineering-like practices (e.g., construction of terraces and contour banks for controlling water erosion), or forest barriers and strip cultivation for controlling wind erosion. In eroded soils, the advance of erosion gullies and sand dunes can be limited by increasing plant cover, among other practices. Experience available worldwide shows that restoring natural ecosystems and their infrastructure is a cost-effective means to address soil erosion, habitat loss, and water quality while engaging communities in activities to reduce flood risks.

Despite the partial information and the methodological differences used by different countries in assessing soil erosion, the available modelling data (Table 13) reveals already high worrying

[258] Zdruli, P. (2014) - Land Resources of the Mediterranean: Status, Pressures, Trends and Impacts on Regional Future Development, Land Degradation and Development, 25 (4): 373-384.

[259] Dorin, B., Paillard, S. and Treyer, S. (2010) – Agrimonde. Scenarios and Challenges for Feeding the World in 2050. INRA, CIRAD. OECD Workshop "Long-Term Scenarios Supporting Robust Policies for Global Agriculture and Food. Paris 21-22, October 2010, 25 pp.

[260] Ferreira, Carla S.S., Seifollahi-Aghmiuni, Samaneh, Destouni, G., Navid Ghajarnia, N., Kalantari, Z. (2022) - Soil degradation in the European Mediterranean region: Processes, status and consequences. *Science of The Total Environment*, Vol 805, 150106, 17 pp. [https://doi.org/10.1016/j.scitotenv.2021.150106]

[261] Williams, M. et al. (2016) – The Anthropocene: a conspicuous stratigraphical signal of anthropogenic changes in production and consumption across the biosphere. Earth's Future. 4: 34-53. [DOI: 10.1002/2015EF000339]

[262] Chappel, A., Baldock, J., Sanderman, J. (2016) – The global significance or omitting soil erosion from soil organic carbon cycling schemes. *Nature Climate Change* 6: 187-191

[263] Smith, P., House, Joanna I., Bustamente, M., Sobocká, J. et al. (2015) – Global change pressures on soils from land use and management. *Global Change Biology* 22(3): 1008-1028.

levels that will tend to exacerbate the consequences of climate change and the already mentioned productivity losses of Mediterranean agriculture. The UNEP/Map[264] and Plan Blue (2020) identifies Mediterranean Europe as an area with a soil loss rate above 20 t/ha/year and refers to it as a global hot spot.

Table 13 - Average soil loss rate per EU-Mediterranean country (all land, arable lands) and share of EU soil loss

Countries	Estimated soil loss rate (t ha^{-1} yr^{-1})		% of the total soil loss in in EU
	Overall mean	Mean of arable land	
Cyprus	2.89	1.85	0.25
Spain	3.94	4.27	19.61
France	2.25	1.99	11.85
Greece	4.13	2.77	5.31
Croatia	3.16	1.67	1.74
Italy	8.46	8.36	24.13
Malta	6.09	15.93	0.01
Portugal	2.31	2.94	2.01

Source: Panagos[265] et al., 2015

As caused by improper agricultural practices and overgrazing, anthropogenic soil interventions accelerate erosion and has repercussions on carbon (soil organic carbon represents 25 % of the full potential of natural climate solutions) and phosphorus emissions. Human-induced erosion accounts for as much as one-third of the carbon emissions that result from land-use change (Wang[266] et al., 2017). Moreover, on much of the global farmland, soil is lost at higher rates through erosion than what can be replenished through natural pedogenesis processes (Amundson[267] et al., 2015). By contrast, deposition of eroded sediment can also sequester carbon (Lal[268], 2001). So, understanding the global feedback of soil carbon to climate change is a major challenge for informing conservative soil policies.

Beyond carbon, phosphorus is another essential element in terrestrial ecosystems that is vital for agriculture. It, too, can be dislocated and transported in dust emissions caused by wind erosion (Katra[269] et al., 2016). Recently, attention has been given to the deposition effects that may increase the fertility of weathered soils offsite. For example, dust from the Sahara may contribute

---

264 UNEP/Map and Plan Blue (2020) – State of Environment and Development in the Mediterranean. United Nations Environment Programme/Mediterranean Action Plan and Plan Bleu. Nairobi

265 Panagos, P., Borrelli, P., Poesen, J., Ballabio, C., Lugato, E., Meusburger, K., Montanarella, L. & Alewell, C. (2015) - The new assessment of soil loss by water erosion in Europe. *Environmental Science & Policy*, *54*: 438-447

266 Wang, Z., Hoffmann, T., Six, J., Kaplan, J. O. et al. (2017) – Human-induced erosion has offset one-third of carbon emissions from land cover change. *Nature Climate Change*, 7: 345-349.

267 Amundson, R., Berhe, A., Hopmans, J.W., Olson, C., Sztein, E. and Sparks, D. L. (2015) – Soil and human security in the 21st century. *Science*, 348 (625). [DOI: 10.1126/science 1261071]

268 Lal, R. (2001) – Soil degradation by erosion. *Land Degradation and Development,* 12: 519-539.

269 Katra, I., Gross, A., Swet, N., et al. (2016) - *Substantial dust loss of bioavailable phosphorus from agricultural soils* 6(1): 24736. [DOI: 1038/srep24736]

phosphorus to America´s tropical forests (Mills[270] et al., 2004). Dust loadings and related air pollution hazards (from fine particles that affect health) are projected to generally decrease in many regions of the Sahara and Sahel due to the changing winds. Dust emissions from cultivated areas may also accelerate the eutrophication of inland lakes where dust is eventually deposited.

Erosion associated with human activities affects land productivity and has economic effects on-site and off-site. The landowner mainly absorbs on-site costs that directly affect farm or pasture production. Off-site costs are primarily borne by society at large through attempts to mitigate their impacts (Telles[271], 2011).

On-site loss of topsoil is the most severe and affects both short-term and long-term land productivity through losses in fertility, water-holding capacity, and changes in soil structure. Management and control of soil erosion may prevent organic carbon losses in water or wind-transported sediments. However, since the final fate of eroded material is still debated, ranging from a source of 1.36 - 3.67 Gt CO_2eq year^{-1} (Lal[272], 2004) to a sink of 0.44 - 3.67 Gt CO_2eq year^{-1} (Smith[273] et al., 2001; Van Oost[274] et al., 2007), the overall effect of erosion control on mitigation is context specific and still highly uncertain at the global level (Hoffmann[275] et al., 2013).

Increasing food productivity through sustainable intensification improves farm incomes and allows households to build assets for use in times of stress, enhancing resilience (Campbell[276] et al., 2014). By reducing pressure on land and increasing crop productivity, increased food production could be beneficial for adaptation. Pretty[277] et al. (2018) report that globally, 163 million farms occupying 4.53 Mkm^2 have passed a redesign threshold by applying sustainable intensification practices, suggesting the minimum number of people benefiting from increased productivity and adaptation benefits under sustainable intensification should be higher than 163 million.

5.9 - Changes in surface albedo

There is high confidence that changes in land conditions from human use or climate change affect regional and global climate. This is driven by changes in emissions or removals of GHG by

---

[270] Mills, M.M., Ridame, C., Davey, j. La Roche, Geider, R. J. (2004) – Iron and phosphorus co-limit nitrogen fixation in the eastern tropical North Atlantic. Nature 429: 292-294

[271] Telles, T. S., Guimarães M. de F., Dechen, A.C.F. (2011) – The costs of soil erosion. *Revista Brasileira de Ciência do Solo* 35: 287-298.

[272] Lal, R. (2014). - *Soil carbon management and climate change*. In: A. E. Hartemink, & K. McSweeney (Eds.), *Soil carbon* (pp. 327–335). Cham, Switzerland: Springer International Publishing. [https ://doi.org/10.1007/978-3-319-04084-4_35]

[273] Smith, S. V., Renwick, W. H., Buddemeier, R. W., & Crossland, C. J. (2001) - Budgets of soil erosion and deposition for sediments and sedimentary organic carbon across the conterminous United States. *Global Biogeochemical Cycles*, 15(3): 697-707 [https ://doi.org/10.1029/2000GB001341]

[274] Van Oost, K., Quine, T. A., Govers, G., De Gryze, S., Six, J., Harden, J. W., Giraldez, J. V. (2007) - The impact of agricultural soil erosion on the global carbon cycle. *Science*, 318(5850), 626-629.

[275] Hoffmann, T., Mudd, S., Van Oost, K., Verstraeten, G., Erkens, G., Lang, A., Aalto, R. (2013) - Humans and the missing C-sink: Erosion and burial of soil carbon through time. *Earth Surface Dynamics*, 1(1): 45-52.

[276] Campbell, B. M., Thornton, P., Zougmoré, R., van Asten, P., & Lipper, L. (2014) - Sustainable intensification: What is its role in climate smart agriculture? Current Opinion in Environmental Sustainability, 8, 39–43. [https ://doi.org/10.1016/J.COSUST.2014.07.002]

[277] Pretty, J., Benton, T. G., Bharucha, Z. P., Dicks, L. V., Flora, C. B., Godfray, H. C. J., Pierzynski, G. (2018) - Global assessment of agricultural system redesign for sustainable intensification. *Nature Sustainability*, 1(8): 441-446. [https ://doi.org/10.1038/s41893-018-0114-0]

the biogeochemical processes and by changes in the surface albedo. Although albedo is not the only source of biophysical land-based climate forcing, one must consider its importance due to the existing relationships with land cover in redistributing of energy and water vapour. The radiative forcing from changes in albedo induced by land-use changes was estimated to be around –0.15 Wm^{-2} [–0.25 to –0.05] (Myhre[278] et al., 2013).

From the perspective of land management decisions, it is interesting to know whether these changes are beneficial from the point of view of containing aridity. It is known that any land change that redistributes energy and water vapour between the land and the atmosphere influences the local climate. So, increasing surface albedo in dryland regions will impact the local environment, decrease surface temperature and precipitation, and provide positive feedback on the albedo (Charney[279] et al. 1975). This albedo feedback can occur in desert regions worldwide (Zeng[280] and Yoon 2009). Similar albedo feedback has also been found in regional studies in Australia (Evans[281] et al., 2017), South America (Lee and Berbery[282], 2012) and the USA (Zaitchik[283] et al., 2003).

Recent work has also found albedo in dryland regions can be associated with soil surface communities of lichens, mosses, and cyanobacteria (Rodriguez-Caballero[284] et al., 2018). These communities compose the soil crust in these ecosystems and directly influence the albedo due to the sparse vegetation cover. These communities are susceptible to climate changes, with field experiments indicating albedo greater than 30% is possible. Thus, although with limited evidence, there is a high agreement that changes in these communities could trigger negative surface albedo feedback processes (Rutherford[285] et al., 2017).

A further pertinent feedback relationship exists between changes in land cover, albedo, carbon stocks and associated GHG emissions, particularly in drylands with low levels of cloud cover. One of the first studies to focus on the subject was that by Rotenberg[286] and Yakir (2010), who used the concept of 'radiative forcing' to compare the relative climatic effect of a change in albedo with a change in atmospheric GHGs due to the presence of forest within drylands. Based on this analysis, it was estimated that between 1970 and 2005, the change in surface albedo due to

---

[278] Myhre, G., Shindell, D., Bréon, F.M., Collins, W., Fuglestvedt, J., Huang, J., Koch, D., Lamarque, J.F., Lee, D., Mendoza, B., Nakajima, T., Robock, A., Stephens, G., Takemura, T. and Zhang, H. (2013) - Anthropogenic and Natural Radiative Forcing. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [Stocker, T.F., D. Qin, G.-K. Plattner, M. Tignor, S.K. Allen, J. Boschung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)]. Cambridge University Press, Cambridge, UK pp. 659–740.

[279] Charney, J.G., 1975: Dynamics of deserts and drought in the Sahel. *Q. J. R. Meteorol. Soc.*, 101: 193–202, [doi:10.1002/qj.49710142802].

[280] Zeng, N., and J. Yoon, J. (2009) - Expansion of the world's deserts due to vegetation-albedo feedback under global warming. *Geophys. Res. Lett.*, 36, L17401, [doi:10.1029/2009GL039699]

[281] Evans, S., Ginoux, P., Malyshev, S. and Shevliakova, E. (2016) - Climate-vegetation interaction and amplification of Australian dust variability. Geophys. Res. Lett., **43**, 11,823-11,830.

[282] Lee, X. et al., 2011: Observed increase in local cooling effect of deforestation at higher latitudes. *Nature*, 479: 384–387, [doi:10.1038/nature10588].

[283] Zaitchik, B.F., Macalady, A.K., Bonneau, L. R. and Smith, R.B. (2003) – Europe's heat wave: A satellite view of impacts and land-atmosphere feedback. *Int. J. Climatol.*, 26: 743-769 [doi: 10.1002/joc.1280].

[284] Rodriguez-Caballero, E., J. Belnap, J., Büdel, B., Crutzen, P.J., Andreae, M.O., Pöschl, U., and B. Weber, B. (2018) Dryland photoautotrophic soil surface communities endangered by global change. *Nat. Geosci.*, 11: 185–189, [doi:10.1038/s41561-018-0072-1].

[285] Rutherford, W.A., Painter, T.H., Ferrenberg, S., Belnap, J., Okin, G.S., Flagg, C. and Reed, S.C. (2017) Albedo feedback to future climate via climate change impacts on dryland biocrusts. *Sci. Rep.*, 7, 44188, [doi:10.1038/srep44188].

[286] Rotenberg, E. and Yakir, D. (2010) – Contribution of semi-arid forests to the climate system. Science, 327: 451- 454 [doi: 10.1126/science.1179998].

degradation of semi-arid areas had decreased radiative forcing by an amount equivalent to approximately 20% of global anthropogenic GHG emissions.

With regards to future climate effects, projections of global and regional climate models conclude that under all representative concentration pathways (RCPs), potential evapotranspiration (PET) would increase worldwide as a consequence of rising surface temperatures and surface water vapour deficit, and consequently, there would be associated changes in aridity indices that depend on this variable (Dominguez[287] et al., 2010; Fu[288] et al., 2016; Koutroulis[289], 2019). Due to a significant increase in PET and a decrease in precipitation over some subtropical land areas, the aridity index will decrease in some drylands (Zhao[290] and Dai, 2015). One model estimates approximately a 10% increase in hyper-arid regions globally. Observations in recent decades indicate that the Hadley cell has expanded poleward in both hemispheres (Hu[291] and Fu, 2007; Seidel[292] and Randel, 2007). Under all RCPs, it would continue expanding. This expansion leads to the poleward extension of subtropical dry zones and, hence, an increase in drylands on the poleward edge (Scheff[293] and Frierson, 2012). Overall, this suggests that while aridity will increase in some places, there is insufficient evidence to suggest a global change in dryland aridity.

Regional modelling studies confirm the outcomes of Global Climate Models. According to the AR5 Report (IPCC, 2013), decreases in soil moisture are detected in the Mediterranean, southwest USA, and southern African regions. This is in line with alterations in the Hadley circulation and higher surface temperatures. This surface drying will continue to the end of this century under the RCP8.5 scenario with higher confidence. Ramarao[294] et al. (2015) showed that climate projection during the 21st century, based on the RCP4.5 scenario, indicated the possibility of detecting a summer-time soil drying signal over the Indian region in response to climate change. The IPCC Special Report on Global Warming of 1.5°C (SR15) (Hoegh-Guldberg[295] et al., 2018) concluded with 'medium confidence' that a global warming by more than 1.5 °C increases

---

[287] Dominguez, F., Caño, J. and Valdes, J. (2010) - IPCC – AR4 Climate simulations for the South-western USA: The importance of future ENSO projections. *Clim. Change*, 99: 499-514 [doi: 10.1007/s10584-009-9672-5].

[288] Fu, Q., Lin L., Huang, J., Feng, S., and Gettelman, A. (2016) - Changes in terrestrial aridity for the period 850-2080 from the community earth system model. *J. Geophys. Res.*, **121**, 2857-2873, [doi:10.1002/2015JD024075].

[289] Koutroulis, A.G. (2019) – Dryland changes under different levels of global warning. *Sci. Total Environ*. 655: 482-511, [doi: 10.1016/J.SCITOTENV.2018.11.215].

[290] Zhao, T. and Dai, A. (2015) - The magnitude and causes of global drought changes in the twenty-first century under low-moderate emissions scenario. *J. Clim.*, 28: 4490-4512, [doi: 10.1175/JCLI-D-14-00363.1].

[291] Hu, Y., and Fu, Q. (2007) - Observed poleward expansion of the Hadley circulation since 1979. *Atmos. Chem. Phys*., 7: 5229-5236, [doi: 10.5194/ acp-7-5229-2007].

[292] Seidel, D.J., and Randel, W.J. (2007) - Recent widening of the tropical belt: Evidence from tropopause observations. *J. Geophys. Res.*, 112, D20113, doi:10.1029/2007JD008861.

[293] Scheff, J., and Frierson, D.M.W (2012) - Robust future precipitation declines in CMIP5 largely reflect the poleward expansion of model subtropical dry zones. *Geophys. Res. Lett.*, 39, [doi:10.1029/2012GL052910].

[294] Ramarao, M.V.S., Krishnan, R., Sanjay, J. and Sabin, T.P. (2015) - Understanding land surface response to changing South Asian monsoon in a warming climate. *Earth Syst. Dyn.*, 6: 569–582, [doi: 10.5194/esd-6-569-2015].

[295] Hoegh-Guldberg, O., Jacob, D., Taylor, M., Bindi, M., Brown, S., Camilloni, I., Diedhiou, A., Djalante, R., Ebi, K.L., Engelbrecht, F., Guiot, J., Hijioka, Y., Mehrotra, S., Payne, A., Seneviratne, S.I., Thomas, A., Warren, R. and Zhou, G. (2018) - Impacts of 1.5 °C of Global Warming on Natural and Human-Systems. In: *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways, in the context of strengthening the global response to the threat of climate change, sustainable development, and efforts to eradicate poverty* [Masson-Delmotte, V., Zhai, P., Pörtner, H.O., Roberts, D., J. Skea, J., Shukla, P.R., Pirani, A., Moufouma - Okia, W., Péan, C., Pidcock, R., Connors, S., Matthews, J.B.R., Chen, Y., Zhou, X., Gomis, M.I., Lonnoy, E., Maycock, T., Tignor, M. and Waterfield, T.(eds.)]. pp. 175–311.

considerably the risk of aridity for the Mediterranean area and southern Africa. Schewe[296] and Levermann (2017) show up to 300% increases in the Central Sahel rainfall by the end of the century. Warming could trigger an intensification of monsoonal precipitation due to increases in ocean moisture availability.

5.10 – Foreseeable climate change impacts on crops

The future of food and agriculture, comprising all agricultural sub-sectors, faces uncertainties that give rise to serious concerns regarding their performance, sustainability, and capacity to satisfy the needs of an increasing population. Uncertainties revolve around different factors, including population growth, dietary choices, technological progress, income distribution, the state of climate change, and the social and state of environment. Despite numerous studies to predict agriculture output and food security, FAO[297] (2018) mentioned that nobody precisely knows how these factors will evolve; however, they will undoubtedly shape the future. What we do know is that, until now, much of humanity's progress has come at a considerable cost to the environment. To produce more food and other non-food agricultural goods, intensified agrarian production processes and forest clearing have led to the degradation of natural resources and are contributing to climate change.

The future will not look promising if we continue to address these challenges with a business-as-usual approach (BAU). Despite the uncertainties, there is no doubt that sustainable food and agriculture systems cannot be achieved without significant additional efforts.

There are several ways in which climate change may affect agricultural activity. Four types of direct impacts can be discerned (Nelson[298] et al., 2010): (i) biological processes affecting crops and animals; (ii) environmental and physical processes, which affect production at the landscape, watershed, or community levels; (iii) human health; and (iv) non-agricultural livelihoods. There will also be indirect effects, including (i) off-site impacts and (ii) effects of adaptation and mitigation interventions.

The impacts of climate change on agriculture food systems will not be felt evenly. The degree of vulnerability of these systems to climate change is contingent on a wide range of local environmental, policy, institutional settings, and management factors. Key factors include local soil conditions, the type and variety of crops that are grown, the type and objectives of the management regimes, the extent and support from governments, the ability of key stakeholders to undertake the necessary remedial steps to address climate changes and extend of knowledge and awareness of expected changes in climate. Despite the incertitude in dealing with multidimensional variables, there is a consensus that moderate warming would benefit cereal and pasture yields at mid-to-high latitudes. Still, even slight warming decreases yields in seasonally dry and tropical regions (Parry[299] et al., 2007). Further warming would have increasingly negative impacts in all regions.

---

[296] Schewe, J. and Levermann, A. - (2017) – Non-linear intensification of Sahel rainfall as a possible dynamic response to future warming. *Earth Syst. Dynam.*, 8: 495-505, [doi: 10.5194/esd-8-495-2017].

[297] FAO (2018) – The future of fod and agriculture – Alternative pathways to 2050. Rome 224.

[298] Nelson, V., Morton, J.F., Burt, P., Chancellor, T. and Pound, B. (2010) - *Climate change, agriculture and fair trade: identifying the challenges and opportunities*. NRI Working Paper Series: Climate Change, Agriculture and Natural Resources. Natural Resources Institute, Chatham, UK. [www.nri.org/docs/d4679-10_ftf_climate_agri_web.pdf].

[299] Parry, M.L., Canziani, O.F., Palutikof, J.P. et al. (2007) - Technical summary. p 23–78. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (eds). *Climate change2007: impacts, adaptation and vulnerability.*

Until the late 1990s, FAO projections (Agriculture: Towards, 2010) on the state of agriculture for the coming decades did not include the potential effects of anthropogenic climate impacts. These projections did not consider changes in agroclimatic conditions due to greenhouse effects (including changes in precipitation regimes, increased temperatures, increased CO_2 emissions, and nitrogen deposition), which are predicted to be greater than any natural climatic variation throughout the last thousands of years. The anthropogenic impacts resulted from growing aspirations for greater well-being, with the associated demands on natural resources at a global and regional level. Projections thus focused on the expected increase in human populations, their basic needs, and especially on terrestrial resources and water, to provide them with the necessary food, fibre, animal feed, forest products and living space. However, although the limitations of those variables are recognized today, there can be no doubt that the increase in population, the change in eating habits, and their ability to influence land cover and use will continue to be the predominant factors.

One must also consider that the last 15 years have seen a significant evolution in global discourses related to food security, nutrition, and food (Gitz [300]et al., 2021): greater emphasis is now placed on nutrition, on the environmental impacts of food systems, in their capacity to produce healthy diets for all sustainably, and on their resilience to climate change and other risks. Within this movement, the emphasis given to the contribution of forests, trees and agroforestry to food security and nutrition represented a significant shift from the old paradigm of considering the focus of food security almost exclusively in staple food production. Globally, despite the more than 300,000 known edible plants (Millennium[301] Ecosystem Assessment, 2005) only 15 crops and 14 animal species grown mostly in low-diversity production systems nowadays provide 90% of humanity's energy intake (Antonelli[302], et al., 2020): rice, maize, and wheat together account for 48% of average daily calories (FAO[303], 2018); the Cavendish banana accounts for 99.9% of all bananas eaten globally. This crop concentration reflects an absence of a comprehensive, system-wide approach to explaining the roles of agroforestry in biodiversity management and protection.

Regarding the value of agricultural production in the Mediterranean region and understanding the particular vulnerability of this region's agriculture, it can be seen that about half of its agricultural production value comes from four crops: grapes (14%), wheat, tomatoes, and olives (9% each). Mediterranean countries produce about 90% of the global supply of the last three (FAO[304], 2017). The wine industry, for instance, in France, Italy, Spain and Portugal produces about half of the world's wine and a little more than 80% of the wine made in the European Union. In addition, the wine industry directly employs some million people, mainly in rural areas and supports other sectors such as tourism. This excessive specialization of the food

---

Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK.

[300] Gitz, V., Pingault, N., Meybeck, A., Ickowitz, A., et. al. (2021) – Contributing of forests and trees to food security and nutrition. FTA Brief, 5 Bogor, Indonesia: CIFOR. [https://doi.org/10.17528/cifor/008006]

[301] Millennium Ecosystem Assessment (2005) – Ecosystems and Human Well Being: Synthesis. Island Press, Washington DC. 140 pp.

[302] Antonelli, A., Fry, C., Smith, R.J., Simmonds, M.S.J., Kersey, P.J., Pritchard, H.W, Abbo, M., Acedo, C., et. al. (2020) – *State of the Worls's Plants and Fungi*. Kew Royal Botanic Gardens. [https://doi.org/10.34885/172]

[303] FAO (Food and Agriculture Organization) (2018) – *Sustainable agriculture for biodiversity – Biodiversity for sustainable agriculture*. FAO: Rome [https://www.fao.org/documents/card/en/c/85baf9c5-ea7f-4e25-812f-737755[a]8b320]

[304] FAO (2017) – FAOSTAT (based on 2017 production values. Food and Agriculture Organization of the United Nations, Rome

production base, which translates into a consequential reduction in genetic variability, leaves the food supply vulnerable to diseases and pests and reduces the resilience of food production systems to increasingly erratic climates (Bellard[305] et. al, 2012).

In short, we have witnessed a massive dietary shift from primarily plant-based diets characterised by high fibre and complex carbohydrates with small amounts of animal foods to diets dominated by commodity crops such as soy and oil palm, high in fats and oils, meats, and refined carbohydrates. For these reasons, the sustainability of food systems and the ecosystem services supporting them is increasingly prominent in food security and nutrition debates and discussions on climate change, biodiversity, and other global environmental issues. Yet, as mentioned by Ickowitz[306] et al. (2021), "*despite the importance of forests and other tree-based systems to food security and nutrition, the landscapes that provide tree products and services are changing rapidly and are being lost even before their roles are fully understood.*"

The risks associated with climate change and difficulties of its assessment lie in the complex of interconnected and interdependent components, within a decision-making environment concerning food systems that is very fragmented, with a wide range of voices from different-interest groups and agendas, with diverse institutional and agro-ecological constrains in countries and territories of the Mediterranean. These unprecedent challenges are complex and thus require solutions that are systemic and dynamic, that go beyond single disciplinary approaches and actively engage the voices of food systems stakeholders (Fig. 30).

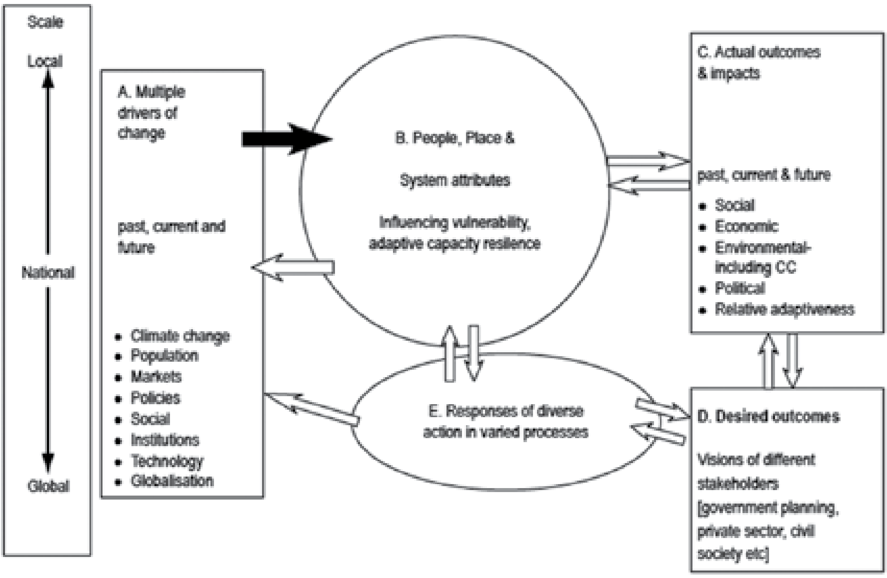


Fig. 30 - Complexity of the agriculture systems
Adapt. from Nelson[307] et al. (2008)

---

[305] Bellard, C., Bertelmeister, C., Leadley, P., Thuiller, W., & Courchamp, F. (2012) – Impacts of Climate Change on the Future of Biodiversity. *Ecology Letters*, 15: 365-577.

[306] Ickowitz, Amy, McMullin, Stepha (2021) – *Food Security and Nutrition*. FTA Highlight of a Decade 2011-2021. CGIAR, 50 pp.

[307] Nelson, V., Lamboll, R., Arendse, A. (2008) – *Climate change adaptative capacity and development Background paper*. DSA-DFID policy Forum 2008: Policy Forum 2008: International Development in the Face of Climate Change: Beyond mainstreaming? pp.15. [http://climateanddevelopment.nri.org/ papers.htm].

If these systems are treated independently, the response will be too fragmented and difficult to integrate into complex national strategies. It is now held that agriculture can also affect the environment and climate, and vice versa. These environmental impacts on global food systems, in terms of deforestation, soil degradation, loss of habitat and biodiversity, create a negative feedback loop that threatens the very ability of ecosystems to produce enough healthy food in the future if not properly managed (IPBES[308], 2018).

This means that in terms of analysing the impacts of climate change and the design of intervention policies to minimise them, it is necessary to consider that not only the climate is changing, but also human societies and agricultural production with their biological limitations, technological and land availability. The design of intervention policies requires the availability of information that responds to the following: i) in the context of climate change, how will natural resources and demography be affected in the next 70 years? ii) how can rural development and agricultural system sustainability be compatible? iii) does the newly available and predictable knowledge offer the potential to increase production without irreparably losing natural resources, such as soil or biodiversity? iv) will it be possible to transform agriculture into a more moderate GHG emitter and make food systems more sustainable? v) what will be the potential socioeconomic impacts of climate change?

The spatial nature of physical climate change means that Mediterranean countries will predictably face varying risks and associate socioeconomic costs relative to the European continent. The highest costs are likely to fall on regions that depend largely on agricultural economic output - or whose food system heavily depends on foreign markets - or tourism. In these areas, where we include Portugal and Southern Europe in general, we could see significant reductions in income and employment and feel knock-on effects if, for example, the holiday property market weakens in regions often prone to the dangers of higher temperature spikes, benefiting, in these situations, the north of Europe. This divergence may increase inequality across the continent as impacts will be uneven across countries and within the continent, accentuating the north-south gap in various socioeconomic indicators.

Over the last thirty years, many simulations have focused on GCM double CO_2 equilibrium scenarios that show few robust conclusions regarding their magnitude or direction of predictable effects for individual countries. Potential future climate change is also uncertain due to the recognized role of sulphate aerosols, which may partially offset expected warming due to increased CO_2 concentrations (Reilly[309], 1996). Different impact methodologies also produce varied results of direct influences on crop yields, even in the same region and climate scenarios. Agricultural yields are mostly site-specific, which means differences in soils, plant varieties, socioeconomic environment, and process technology used, which makes it difficult, at a national level, to get a complete picture of the real impact of climate change on food production. However, despite these uncertainties, there is a robust conclusion: climate change can significantly alter agricultural and forestry productivity in most locations, positively or negatively. Thus, world crop productivity studies in some areas show regional variations ranging from ± 20 to ± 30%.

---

[308] IPBES (Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services), (2018) – *Thematic assessment report on land degradation and restauration*. Bonn [https://ipbes.net/assessment reports/ldr]

[309] Reilly, John (1996) – Climate Change, Global Agriculture and Regional Vulnerability. In: Highlights from an Expert Consultation on Global Climate Change and Agriculture Production, Chapter 10, 22 pp. FAO, Rome 1996

5.10.1 – General synthesis of likely climate impacts on crops

Hulme[310] (1996) mention four mechanisms in which climate would have a physical effect on crops: i) changes in temperature and precipitation through its effect in altering the agroecological zonation; ii) CO_2 fertilization effects; iii) water availability; iv) Climate variability and the increased frequency of extreme events.

Changes in soil-moisture content and length and time of growing seasons will affect crop yields independently of inputs in fertilizers. At the world level, the current climate, soil, and terrain suitability for a range of rain-fed crops and pasture types has been estimated by Fischer et al. (2002) (Fig. 31a).

Globally, some 3.6 billion ha (about 27% of the Earth's land surface) are too dry for rain-fed agriculture. Considering water availability, only about 1.8% of these dry zones are suitable for producing cereal crops under irrigation. Changes in annual mean runoff are indicative of the mean water availability for vegetation. Projected changes between now and 2100 show some consistent runoff patterns: increases in high latitudes and the wet tropics and decreases in mid-latitudes and some parts of the dry tropics (Fig. 31b).

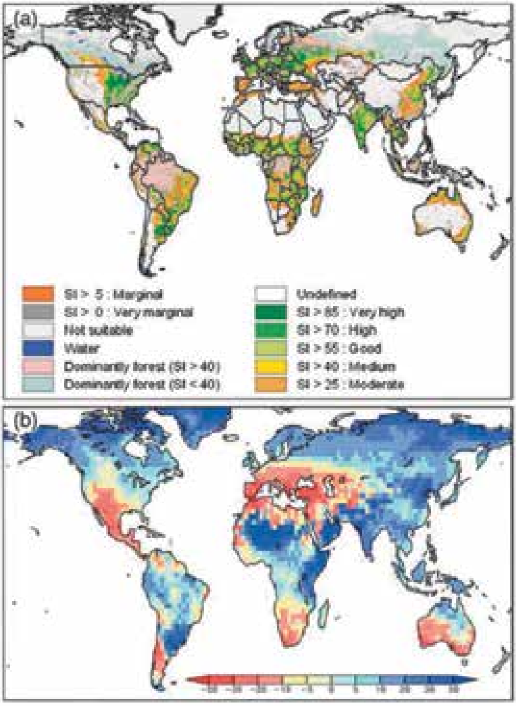


Fig. 31

(a) Current suitability for rain-fed crops (excluding forest ecosystems) SI = suitability index; (b) Ensemble mean percentage change of annual mean runoff between present (1981 to 2000) and 2100.

Source: Fischer[311] et al. (2002) and (Nohara[312] et al., 2006).

---

310 Hulme, Mike, ed. (1996) - Climate Change and Southern Africa. Norwich, United Kingdom: Climatic Research Unit, University of East Anglia.

311 Fischer, G., van Velthuizen, H., Shah, M. and Nachtergaele, F.O. 2002: Global agro-ecological assessment for agriculture in the 21st century: methodology and results. *Research Report* RR-02-02. ISBN 3-7045-0141-7., International Institute forApplied Systems Analysis, Laxenburg, Austria, 119 pp.

312 Nohara, D., A. Kitoh, A., Hosaka, M. and T. Oki, 2006: Impact of climate change on river discharge projected by multimodal ensemble. *J. Hydrometeorol.*, 7: 1076-1089.

Therefore, declines in water availability are projected to affect soe of the areas currently suitable for rain-fed crops (e.g., in the Mediterranean basin) and consequently a decrease in yields is quite likely.

Casual observation of the distribution of plant species tells us that temperature is a significant factor controlling their distribution worldwide. Predicted temperature increases could, therefore, affect the distribution of plant species and, consequently, the distribution of animals associated with them. Temperature affects plant species' distribution and is an important determinant of plant performance within their range. How quickly plants grow and their susceptibility to disease and environmental stress are also influenced by temperature.

Each crop species has a set of temperature thresholds that define upper and lower limits for growth and reproduction, along with ideal temperatures for each stage of development. Currently, plants are grown in areas exposed to temperatures corresponding to their limit values. As temperatures increase over the next century, changes in agricultural production areas may occur because temperatures will no longer occur within the range or during the critical period for optimal growth and yield of cereals or fruits. For example, pollination is one of the most temperature-sensitive phenological phases, and exposure to high temperatures during this period can significantly reduce crop yields and increase the risk of total crop failure. Plants exposed to high night-time temperatures during grain, fibre, or fruit setting also experience lower yields and reduced quality.

Increasing temperatures cause plants to mature and complete their stages of development faster, which may alter the feasibility and profitability of regional crop rotations and field management options, including double-cropping and use of cover crops. Faster growth may create smaller plants, because soil may not be able to supply water or nutrients at required rates, thereby reducing grain, forage, fruit, or fiber production. Increasing temperatures also increase the rate of water use by plants, causing more water stress in areas with variable precipitation.

Estimated reductions of solar radiation in agricultural areas due to increased cloud cover and radiative scattering caused by atmospheric aerosols over the last 60 years are projected to continue. Such reductions may partially offset the CO_2 fertilization effect and temperature-induced acceleration of plant growth.

For vegetables, exposure to temperatures in the range of 1°C to 4°C above optimal for biomass growth moderately reduces yield, and exposure to temperatures more than 5°C to 7°C above optimal often leads to severe, if not total, production losses.

The range of temperature regimes over which a species can successfully maintain photosynthesis will depend on both the genetic variation within the species (genotypic plasticity) and the degree to which individuals can adjust photosynthetic physiology (phenotypic plasticity). For plants which cannot adjust temperature, such plasticity may be particularly important in delimiting the temperature range over which the species can survive.

While many agricultural enterprises have the option to respond to climate changes by shifting crop selection, the development of new cultivars in perennial specialty crops commonly requires 15 to 30 or more years, significantly limiting that sector’s opportunity to adapt by shifting cultivars unless cultivars can be introduced from other areas.

An increase in winter temperatures also affects perennial cropping systems through interactions with plant chilling requirements. All perennial specialty crops have a winter chilling requirement (typically expressed as hours below 10°C and above 0°C) ranging from 200 to 2,000 cumulative hours. Yields will decline if the chilling requirement is not completely satisfied because flower emergence and viability will be low. By the middle to the end of the 21st century, projected air temperature increases, e.g. in California, may make the chilling requirements for fruit and nut trees impossible.

Concerning temperature changes, the increasing number of regional and global simulation studies performed since the TAR[313] (Third Assessment Report) makes it possible to produce synthesis graphs, showing not only changes in yield for key crops against temperature (a proxy for both time and severity of climate change), but also other important climate and management factors, such as changes in precipitation or adaptation strategies.

Higher temperatures will extend the growing seasons in higher and middle latitudes, thus benefiting countries in these regions. However, in less fertile soils at higher latitudes, we did not find enough information on the beneficial effect of extending the growing season. Hence, it is almost impossible at this stage to infer to what extent soil conditions will constrain sustainable agriculture. The other factors (precipitation levels, fertilizer use, available irrigation, transport, and market conditions) significantly influence the outcome. In contrast, higher temperatures in lower latitudes are expected to negatively affect growing conditions, especially in areas close to or at an optimal level for crop growth. Combined changes in temperature and precipitation will also be affected by irrigation availability and demand.

Heat stress reduces fruiting and accelerates annual vegetable development, resulting in yield losses and impaired quality, leading to more significant food loss and waste. Longer growing seasons in places where water availability was not restrictive allowed more substantial areas of crops to be cultivated and contribute to higher annual yields. These conditions are rarely found in most Mediterranean countries, where the increase in temperature corresponds almost invariably to water scarcity.

Under a climate change scenario, production from traditional winemaking regions in the Mediterranean countries could diminish since grapevines are highly susceptible to temperature and precipitation. Researchers estimated that temperature variations during the growing season could explain 10 to 60% of vintage ratings (Gregory[314] et al., 2005). Higher temperatures usually reduce grape quality by increasing sugar levels and decreasing acidity. Another potential hazard to grapes is related to higher water stresses. While mild water stress enhances grape quality for red wines, severe water stress reduces yields. Production can also be lost due to severe hailstorms, and climate change may contribute to their incidence. Researchers project that kinetic energy from hailstorms will increase by 40% in France between 2000 and 2040 (Dessens[315], et al., 2015). Some studies project a fall of up to 70% in the Mediterranean area suitable for viticulture, motivated by a wide range of adverse effects in grape yields due to climate change.

As the Mediterranean region becomes warmer, it is also likely that specific grape varieties (e.g. Merlot in Bordeaux) will no longer grow where they do now, while at the same time new varieties

---

[313] Third Assessment Report (2001). Climate Change 2001: Synthesis Report (Wembley, UK), 34 pp. [www.ipcc.ch/site/assets/uploads/2018/03/spm.pdf]

[314] Gregory, V.J., White, M.A., Cooper, O.R., Storchmann, K. (2005) – Climate change and global wine quality. *Climate Change*, 73 (3): 319-343

[315] Dessens, J., Berthet, C., and Sanchez, L. (2015) - Change in hailstorm size distribution with an increase in the melting level height. *Atmospheric Research*, 158 (1)

may survive. Certain growing areas in Italy, Portugal and Spain could predicably experience large declines in production or even collapse (Fraga[316], et al., 2016).

The current evaluations of the impact of changing temperatures have focused on the effect of average higher temperatures. However, increases in minimum air temperature may likely be more significant in their effects on growth and phenology (Hatfield[317] et al., 2011). Minimum air temperatures are more likely to increase under climate change (Knowles[318] et al., 2006). Although maximum temperatures are affected by local conditions, especially soil water content and evaporative heat loss as soil water evaporates (Alfaro[319] et al., 2006), minimum air temperatures are affected by changes in the mesoscale measurement of atmospheric water vapour content. Therefore, in areas where climate change is expected to cause increased precipitation or where irrigation is prevalent, significant increases in maximum temperatures are less likely to occur compared to drought-prone regions. Minimum air temperatures affect plants' nocturnal respiration rates and can potentially reduce biomass accumulation and crop yields (Hatfield et al., 2011). Welch[320] et al. (2010) found higher minimum temperatures reduced grain yield in rice, while higher maximum temperatures raised yields because the maximum temperature seldom reached the critical optimum temperature for rice. However, under the scenario of future temperature increases, they found maximum temperatures could decrease yields if they are near the upper threshold limit.

An increase in potential evapotranspiration will likely intensify drought stress, especially in semiarid and arid regions in subtropics and Mediterranean areas. For some crops, plant metabolism begins to break down above 40 ^{o}C, and a reduction in growing periods due to accelerated growth can reduce the yields.

As Hatfield[321] and Prueger (2015) mentioned, increased temperature effects significantly impact grain yield more than vegetative growth because of the increased minimum temperatures. These effects are evident in a high rate of senescence, which reduces the ability of the crop to fill the grain or fruit efficiently. Observations in controlled environment studies show that above-normal temperatures significantly reduce maize grain yield during the grain-filling period. Temperature effects interact with the soil water status, suggesting that variation in precipitation coupled with warm temperatures would increase the adverse impact on grain production.

In general terms, Fig. 32, based on the results of 69 studies (Easterling[322] et al, 2007), summarizes yield sensitivity against mean local temperature increase – used as a proxy to

---

[316] Fraga, H., Cortázar Atauri, I.G., Malheiro, A.C., Santos, J.A. (2016) – Modelling climate change impacts on viticultural yield, phenology and stress conditions in Europe. *Global Change Biology*, 22 (11): 3774-3788.

[317] Hatfield, J.L., Boote, K.J., Kimball, B.A., Ziska, L.H., Izaurralde, R.C., Ort, D., Thomson, A.M., Wolfe, D.W. (2011) - Climate impacts on agriculture: implications for crop production *Agron. J.*, 103: 351-370

[318] Knowles, N., Dettinger, M.D., Cayan, D.R. (2006) - Trends in snowfall versus rainfall in the western United States, *J. Clim.*, 19: 4545-4559

[319] Alfaro, E.J., Gershunov, A., Cayan, D. (2006) - Prediction of summer maximum and minimum temperature over the central and western United States: the roles of soil moisture and sea surface temperature. *J. Clim.*, 19: 1407-1421

[320] Welch, J.R., Vincent, J.T., Auffhammer, M., Moya, P.F., Dobermann, A., Dare, D. (2010) - Rice yields in tropical/subtropical Asia exhibit large but opposing sensitivities to minimum and maximum temperatures. *Proc. Natl. Acad. Sci.*, 107: 14562-14567

[321] Hatfield, J.L., and Prueger, J.H. (2015) - Temperature extremes: Effect on plant growth and development. *Weather and Climate Extremes* 10: 4-10

[322] Easterling, W.E., Aggarwal, P.K., Batima, P., Brander, K.M., Erda, L., Howden, S.M., Kirilenko, A., Morton, J., Soussana, J.F., Schmidhuber, J., Tubiello, F.N. (2007) - Food, Fibre and Forest Products, pp. 273-313. In: Parry, O.F., Canziani, O.F., Palutikof, J.P., van der Linden, P.J. and Hanson, C.E. (Eds) Climate change 2007: Impacts, Adaptation and

indicate the magnitude of climate change – of the yield of three most essential cereals (wheat, maize, and rice).

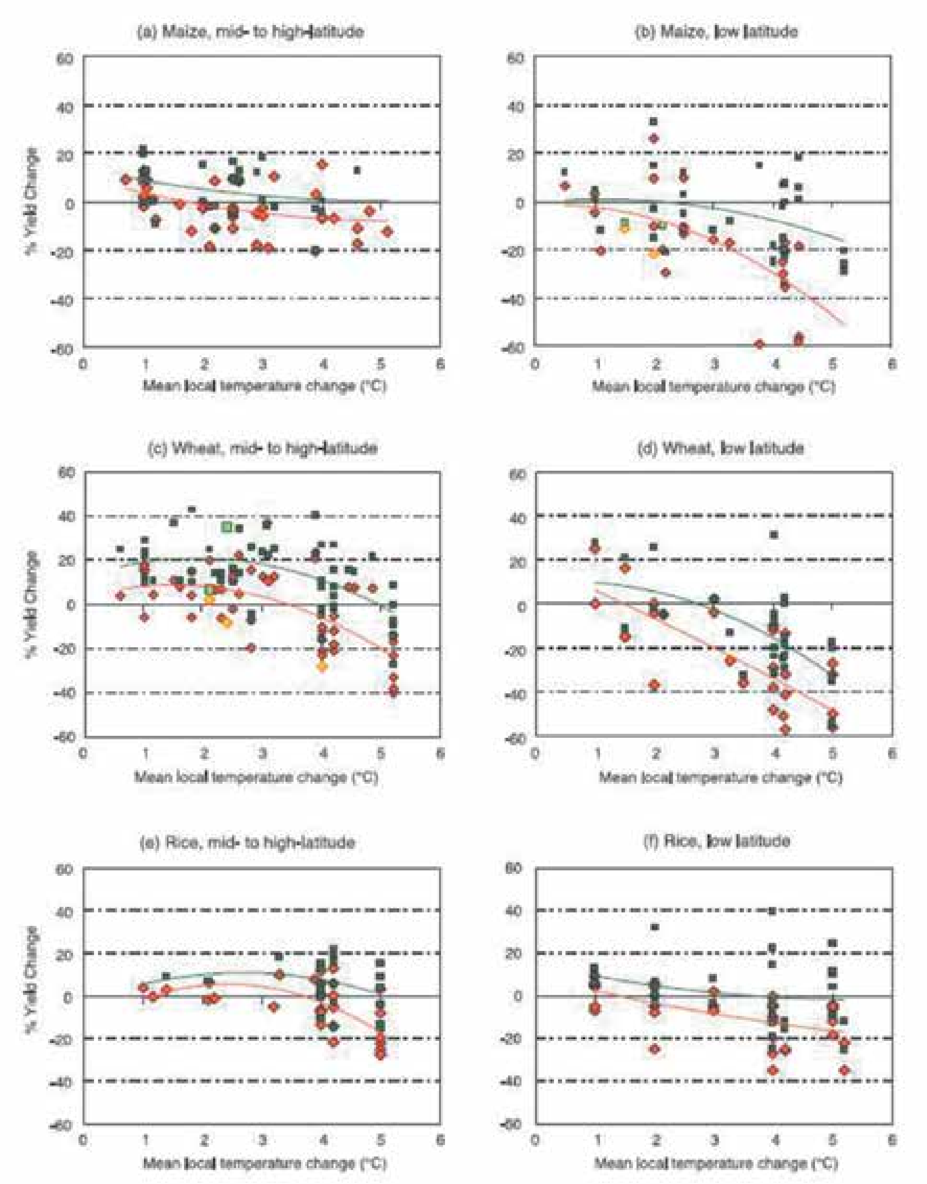


Fig. 32 – Yield sensitivity against mean local temperatures increase in the three most important cereals (wheat, rice, and maize). Red dots – cases without adaptation; Dark green dots – cases with adaptation.

Source: Easterling et al. (2007)

Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the IPCC. Cambridge University Press, Cambridge, UK.

The figure depicts results for temperature increases ranging from about 1-2 ºC, typical of the next several decades, up to the 4-5°C projected for 2080 and beyond. The results of such simulations are generally highly uncertain due to many factors, including large discrepancies in GCM, predictions of regional precipitation change, poor representation of impacts of extreme events and the assumed strength of CO_2 fertilisation.

Nevertheless, these summaries indicate that in mid-to-high latitude regions, moderate to medium local increases in temperature (1 ºC to 3 ºC), across a range of CO_2 concentrations and rainfall changes, can have small beneficial impacts on the main cereal crops. Further warming has increasingly negative effects (medium to low confidence (Fig. 32 a, c, e). In low-latitude regions, these simulations indicate that even moderate temperature increases are likely to have negative yield impacts for major cereal crops (Fig. 32 b, d, f). For temperature increases above 3 ºC, average impacts are stressful to all crops and regions assessed. The low and mid-to-high latitude regions encompass most of the global cereal production area.

The studies summarised in Fig. 32 also indicate that precipitation changes (and associated changes in precipitation/evaporation ratios), may critically shape crop yield responses, over and above the optimal temperature, in agreement with previous analyses.

In synthesis Fig. 32 shows: i) how climate change negatively influences cereal yields harder in low latitude areas in comparison with mid to high latitudes; ii) that adaptation measures including changes in planting time, changes in the cultivar and shifts from rainfed to irrigated conditions where it is viable, alleviates these negative effects; and iii) that C3 and C4 plants cannot be distinguished in their response to climate change, probably because of counterbalancing effects of elevated CO_2 concentrations and associated higher temperatures.

Terrestrial ecosystems have accounted for more than half of the global carbon sink during the last six decades and thus have had a decisive role in mitigating climate warming. Global process-based models attribute part of the increasing land carbon sink to increased vegetation productivity driven by the fertilization effect of increasing atmospheric CO2 concentration, which acts as negative feedback in the climate system.

Results suggests that global production potential, defined by Sivakumar[323] and Valentin (1997) as equivalent to crop yield or Net Primary Productivity (NPP), is threatened at +1°C local temperature change and can accommodate no more than +3 °C before beginning to decline.

Being CO_2 a key factor in photosynthesis, its increase is expected to impact plant growth positively. In a CO_2-rich environment, the larger concentration gradient forces more CO_2 into the plant, while partial closure of the stomata will reduce water losses from the leaf (Rodrigues[324] et al., 2021). As stomatal opening decreases in a high CO_2 environment, water loss from the plant is also reduced, increasing water use efficiency. In optimal conditions of light, moisture and availability of nutrients, this fertilization effect could increase biomass production by 10 to 40% depending on crop type and even to higher levels such as the case in cotton. Earlier and more rapid leaf production is expected and the incremental increase in biomass and the earlier ground cover by the canopy development may also limit water loss by direct soil evaporation.

---

[323] Sivakumar, M.V.K. and Valentin, C. (1997) - Agroecological zones and crop production potential. Phil. Trans. R. Soc. Lond. B, 352: 907-916.

[324] Rodrigues, A.M., Pita, G., Mateus, J., Kurz-Besson, C., Casquilho, M., Cerasoli, S., Gomes, A., and Pereira, J. (2021) – Eight years of continuous carbon fluxes measurements in a Portuguese eucalypt stand under two main events: Drought and felling. *Agricultural and Forest Meteorology*, 151: 493-507

The effects of elevated CO_2 on water-use efficiency may be an advantage for areas with limited precipitation. Other changing climate conditions may either offset or complement such effects. In turn, higher temperatures, for example, will increase the demand for water by crops, increasing the rate of water use. Crops grown on soils with a limiting soil water-holding capacity are likely to experience an increased risk of drought and potential crop failure because of temperature-induced increases in crop water demand, even with improved water-use efficiencies. Conversely, declining trends of near-surface winds over the last several decades and projections for future declines of winds may decrease evapotranspiration of cropping regions.

Some researchers found that these effects are strongest for plants with the C3 photosynthetic pathway, which includes crops such as wheat, rice, and soybean. Carbon dioxide enrichment is also positive - though not as much for C4 plants such as maize, millet, sorghum, and many grasses (and thus weeds). Reilly[325] et al., (1996) estimated that a doubling of carbon dioxide concentrations would lead to yield improvements ranging from 10 – 30 %. Ringius[326] et al. (1996) suggest that water use efficiency will increase in the same range. However, while higher atmospheric concentrations of CO_2 will, by reducing evapotranspiration, improve the water use efficiency of crops and increase the rate of photosynthesis (Darwin[327], 2001), the net result may be moderated by costly pest and weed infestations. At the same time, there is a debate on whether expected productivity increases due to CO_2 have been overestimated, possibly meaning that the fertilization effects in crop yields should have been more apparent than real.

Although there is a general acceptance that changes in CO_2 affects vegetation photosynthesis and directly influence the global carbon cycle, and may have significant impacts on the water cycle and global energy budgets by modifying vegetation transpiration and surface albedo, analyses based on multiple decades of satellite data and long-term observations of surface fluxes at eddy covariance (EC) flux sites, Wang[328], et al. (2020), demonstrated a significant and spatially extensive decrease in the sensitivity of gross primary production (GPP) to CO_2 increment. This declining trend in the forcing of terrestrial carbon sinks by increasing levels of atmospheric CO_2 implies a substantial reduction of the positive effects of increasing atmospheric CO_2 on terrestrial carbon uptake because of the possible limitation of the potential nutrient shortages and water availability in the soils. Despite the remaining uncertainties about current carbon cycle models and their global quantitative effects on the climate system, there seems to be a high probability that this certainly means an increase in society's dependence on future strategies to mitigate the impacts of climate change.

---

[325] Reilly, J., Baethgen, W., Chege, F. E., van de Geijn, S.C., Erda, L., Iglesias, A., Kenny, G., Patterson, D., Rogasik, J., Rötter, R., Rosenzweig, C., Sombroek, W., and Westbrook. J. (1996) - Agriculture in a Changing Climate: Impacts and Adaptation. In: R. T. Watson, M. C. Zinyowera, and R. H. Moss, (eds.), *Climate Change 1995: Impacts, Adaptations, and Mitigation of Climate Change: Scientific-*

Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, United Kingdom and New York, N.Y.: Cambridge University Press.

[326] Ringius, Lasse, Downing, T., Hulme, M., Waughray, D., and Selrod, R. (1996) - *Climate change in Africa: Issues and challenges in agriculture and water for sustainable developmen*t. Report 1996:8, CICERO (Center for International Climate and Environmental Research), University of Oslo.

[327] Darwin, Roy. 2001. Climate Change and Food Security. *Agriculture Information Bulletin* 765(8): 1-2.

[328] Wang, S., Zhang, Y, Ju, W., Chen, J.M., Ciais, P., Cascatti, A. et al (2020) – Recent global decline of CO2 fertilization effects on vegetation photosynthesis. Exeter University, Ore Open Research Exeter. Science. 1-99 [available at: http://hdl.handle.net/10871/124090].

Berry[329] and Roderick (2002) examine the relationship between the observed 20 per cent increase in CO_2 over the last two hundred years and land-use effects on Australian vegetation and conclude that the seasonally green leaves of annual and ephemeral herbaceous vegetation cover are roughly the same over this period. In addition, their results highlighted that the increase in evergreen cover is likely to have been caused by the increase in CO_2 concentrations, but it alone is unlikely to be the sole case of the change.

As shown, anti-transpiration's importance and its fertilisation effects vary with crop type. For example, at double atmospheric CO_2, the biomass production of C3 plants, including major crops such as rice, wheat, potatoes, beans, soybeans, sunflower, groundnut, and cotton, can be expected to increase, on average, by some 30 %, provided other factors are not limiting.

At current atmospheric concentrations of CO_2, C4 plants avoid photorespiration, photosynthesis is saturated, and the effects of high concentrations of CO2 on the assimilation rate are theoretically small or non-existent (Ghannoum[330] et al., 2000). These same authors cited some works that report that the increase in CO_2 concentrations in C4 plants will have no effect under conditions where there is no water stress and other studies that state the opposite, that is, that there are increases in growth under these conditions: the mean increases in biomass accumulation increasing the current CO2 concentration (300 to 400 µmol-1) were 22 to 33% for C4 plants and 40 to 44% for C3 plants.

More recent studies have analysed the sensitivity of several plants to increased CO_2 concentration, considering its fertilising effect. Experimentation reveals that C4 plants are more efficient at current CO_2 levels, but on the other hand, it is C3 plants that respond positively to an increase in CO_2. The response of the photosynthetic rate of the corn plant (plant C4) to increasing concentrations of CO_2 reaches saturation at a concentration of about 450 ppmv. In comparison, the photosynthetic rate of the wheat plant (plant C3) saturates at a concentration of 850 ppmv. The photosynthetic rate of C3 plants is more sensitive to CO_2 variations than that of C4.

Paiva Brandão[331] (2006), simulating the daily photosynthesis for corn and wheat for a given value of conversion of solar radiation to photosynthetically active radiation, shows the effect of CO_2 on the daily growth rate of the crop (Fig. 33).

---

[329] Berry, S. L., and Roderick, M.L. (2002) - CO2 and Land-Use Effects on Australian Vegetation over the Last Two Centuries. *Australian Journal of Botany* 50 (4): 511-531.

[330] Ghannoum, O., von Caemmerer, S., Ziska, L.H. e Conroy, J.P. (2000) - The growth response of C4 plants to rising atmospheric CO2 partial pressure: a reassessment. *Plant, Cell and Environment* 23: 931-942.

[331] Paiva Brandão, A.M.C.A. (2006) – Alterações Climáticas na Agricultura Portuguesa: instrumentos de análise, impactos e medidas de adaptação. (Tese Doutoramento). Universidade Técnica de Lisboa. Instituto Superior de Agronomia. Lisboa, 242 pp.

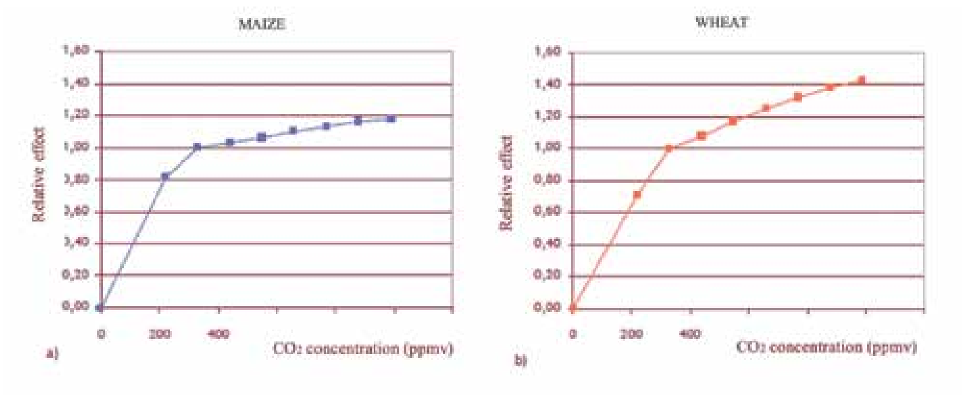


Fig. 33 - Effect of CO_2 concentration on the relative daily growth rate of maize (C4) (a) and wheat (C3) (b)
Source: Paiva Brandão (2006)

This review shows that the results obtained regarding the response of C3 and C4 plants to the increase in CO2 concentrations are still uncertain and require further development and, in a way, better standardization of the experimental procedures. Although based on experimental evidence, previous studies suggested that changes in plant community composition suppressed the CO2 stimulation of plant productivity.

Changes in plant community composition and adaptation mechanisms or interactions with other nutrients, namely N, show that it is still not feasible to disentangle the precise role of these factors at the global scale. On the other hand, the effects of plant physiological acclimation and dynamic changes in species composition are not adequately represented in current models, which need further research investment.

The divergences in these results reveal not only the experimental difficulties of the studies and their relative youth, namely the need for a more integrated approach to other variables such as those resulting from interactions with temperature, namely critical temperatures, and their impact on the reproductive cycle and soil water and nutrients budget. Despite some evidence from field experiments, extrapolation to large-scale field conditions or long-term global or regional food production is still uncertain. One also has to consider that since crop responses to climate change are site-specific and species-dependent, the knowledge of one kind of plant (e.g. annuals) may have little relevance to other species or groupings (e.g. perennials). It should also be noted that under limited soil and water conditions or solar radiation (e.g. through better cloud cover), a higher level of CO_2 may not improve overall yields. In much of our world, such stressful conditions are the rule rather than the exception.

Resolving these discrepancies requires more site-level observations in relatively under-sampled regions and continued investment in space-based satellite observations, which are crucial for monitoring regional changes in carbon uptake (Kaushik[332] et al., 2020) and thorough investigation of the feedback mechanisms that can further limit the long-term benefits of CO_2 fertilization.

---

[332] Kaushik, Aleya, Graham, J., Dorheim, K., Kramer, R., Wang, J. and Byrn, B. (2020) – The Future of the Carbon Cycle in a Changing Climate. Paper presented at AGU Chapman Conference on Understanding Carbon-Climate Feedback, Eos, 101, 11 pp. [https://doi.org/10.1029/2020EO140276].

Another important remark is that higher biomass yield does not necessarily imply higher nutritional quality. Some cereals and forage crops show lower protein content resulting from high CO_2 concentrations (Schmidhuber[333] and Tubiello, 2007). For instance, wheat grown at 546-586 ppm CO_2 has 5.9-12.7 % less protein, 3.7-6.5 % less zinc, and 5.2-7.5 % less iron. Scientists are also finding that micronutrients such as iron and zinc can decline in edible parts of the crops such as wheat, corn, and rice with increasing CO_2 levels. High atmospheric carbon dioxide levels disrupt plants internal chemistry, altering how much protein and other nutrients are produced and internally stored (WB[334], 2021).

In short, as food utilization is an intrinsic component of food security, food quality should not be neglected in studying the effects of CO_2 concentrations on crop production.

The analysis of the effects of carbon fertilization in perennial tree crops, which yield fruit, nuts, and wood, poses complex problems in assessing the impacts of CO_2 and temperature interactions because their yield depends on a phased sequence of development for at least two years. Climatic warming could disrupt this sequence, for example, by providing insufficient winter chilling to synchronize spring bud break or advancing ovule development, leading to poor fruit set in spring (Cannell[335] et al., 1989). The long-term influence of CO_2 on tree growth and its interaction with temperature responses is still very uncertain. For forests, there is reason to believe that shortages in other nutrients may limit the carbon fertilization effect. This is less of a problem with agriculture, where farmers regularly supplement nutrients through fertilizers. The modelling study under the chosen scenario HadCM2 (based on an emission scenario IS92a with a result of a 2.5 ^{o}C increase between 1990 and 2050 in mean temperature and an increase in precipitation of 5-15%) showed that the net annual increments in stem wood of European forest would further increase with an additional 0.9 $m3ha^{-1}yr^{-1}$ compared to the ongoing increase of 4.95 m3ha-1yr-1 under the current climate. Given the anticipated rainfall decrease, this is hardly expected for the Mediterranean forests.

Lutze[336]et al. (1999) report that crop growth under elevated CO_2 led to spring frost damage in field-grown seedlings of snow gum (*Eucalyptus pauciflora* Sieb, ex Spreng), a usually frost-tolerant eucalyptus. Their result suggests that an increase in frost susceptibility may lower likely gains in productivity from CO_2 fertilization. This result clearly will be less critical as frost risk is reduced from higher temperatures. So, the overall benefits of climate change in additional wood products look positive under water availability conditions.

Concerning water availability (or runoff), considered the third critical factor in determining the impact of climate change in many places, several studies suggest that precipitation and the length of the growing season are crucial in determining whether climate change affects positively or negatively the agriculture (Hulme, 1996; Fischer[337] and Velthuizen, 1996; Sivakumar[338] 1992). However, as outlined earlier, constraints abound on the scientific ability to predict trends in rainfall with much certainty. There is less confidence in other parts of the world about precipitation than in other climate changes. Despite finer developments in climate modelling,

---

[333] Schmidhuber, J. and Tubiello, F.N. (2007) – Global food security under climate change: Proceedings of the National Academy of Sciences of the United States of America, 104(50): 19703-19708.

[334] WB (2021) - How do you Feed a Rapidly Warming Planet? - World Bank. Washinhgton DC. [https://www.worldbank.org/en/news/feature/2021/08/25/q-a-how-do-you-feed-a-rapidly-warming planet]

[335] Cannell, M.G.R., Grace, J. and Booth, A. (1989) – Possible impacts of climatic warming on trees and forests in the United Kingdom: a review. Forestry 62: 337-364.

[336] Lutze J. L., Roden, J. S., Holly, C. J., Wolfe, J., Egerton, J. G. and Ball M. C. - (1999). Elevated atmospheric CO_2 promotes frost damage in evergreen tree seedlings. *Plant Cell and Environment* 21(6): 631-635.

[337] Fischer, G., and Van Velthuizen, H.T. (1996) - Climate Change and Global Agricultural Potential Project: A Case Study of Kenya. Laxenburg, Austria: International Institute for Applied Systems Analysis.

[338] Sivakumar, M. V. K. 1992. "Climate change and implications for agriculture in Niger. *Climatic Change* 20: 297-312.

comprehensive regional and subregional precipitation models are still lacking, which limits researchers' ability to reach firm conclusions about precipitation-related effects on agriculture.

Climatic variability and increased frequency of extreme events such as droughts and floods are considered the fourth most important factor to agricultural losses. Higher frequency of droughts is likely to increase pressure on water supplies for numerous reasons ranging from plant transpiration to allocation. In contrast, increases in rainfall intensity in other regions can lead to higher rates of soil erosion, leaching of agricultural chemicals, and runoff that carries livestock waste and nutrients into water bodies. While current climate forecasts are not clear about how extreme events and variability will change across agroclimatic zones, it is expected that adjustment costs are likely to be higher with greater rates of change (Adams[339] and Hurd, 1999).

One area that has received substantial attention is El Niño/Southern oscillation (ENSO). ENSO that has been responsible for considerable variation in both temperature and precipitation. Of particular concern are areas such as Southern Africa where these effects are important. The expected variability of temperature, precipitation, atmospheric carbon content, and extreme events are forecast to have profound effects on plant growth and yields, crops, soils, insects, weeds, diseases, livestock, and water availability in Africa (Adams[340] et al. 1998) and IPCC (1996) for a wide-ranging overview of the likely effects on the agricultural sector. Burton[341] (2001) suggests that expected impacts in dryland areas include reduction in rainfall, rise in temperature, and increased rainfall variability. Some arid areas such as Mauritania, Mali, and Niger may even get higher levels of rainfall. Highland areas are also expected to benefit, since the growing season would be lengthened, and the incidence of frost diminished. In contrast, other, more subhumid zones, are expected to suffer from reductions in rainfall.

In the Northern Hemisphere, we cannot forget that predictable changes in the AMOC could worsen the predictable consequences for the climate of countries along the Mediterranean coast and increase implications for agriculture, particularly those related to:

i. Water availability: Changes in precipitation patterns influenced by the AMOC can directly impact water availability for agricultural purposes. Shifts in rainfall distribution may require adjustments in irrigation practices and water management strategies;
ii. Crop Suitability: Alterations in temperature and precipitation regimes influenced by the AMOC can affect the suitability of certain crops for cultivation along the Mediterranean coast. Agricultural practices and crop selection may need to adapt to changing climate conditions;
iii. Pest and Disease Dynamics: Changes in climate patterns associated with the AMOC can influence the prevalence and distribution of pests and diseases affecting agricultural crops. Agricultural stakeholders may need to implement adaptive measures to mitigate potential impacts on crop yields and productivity.

Although there is a broad consensus that the climate variables relevant to food security and food systems are predominantly temperature and precipitation-related, we cannot forget it is also

339 Adams, Richard M., and B. H. Hurd, B. H. (1999) - Graphically Speaking: Climate Change and Agriculture: Some Regional Implications. *Choices* 14 (1): 22-23.

340 Adams, R. M., McCarl, B. A. ed al. (1998) - Climate Change and U.S. Agriculture: some further evidence. Report prepared for the Electric Power Research Institute as part of the Agricultural Impacts Project of the Climate Change Impacts Program (CCIP).

341 Burton, Ian. (2001) - Vulnerability and Adaptation to Climate Change in the Drylands, The Global Drylands Partnership, WB, Washington, D.C., 133 pp.

critical to include integrated metrics that combine these and other variables (e.g., solar radiation, wind, humidity) and extreme weather and climate events including storm surge.

The revised information shows that climate change will increasingly affect food security. Across Shared Socio-economic Pathways (SSPs) 1, 2, and 3, global crop and economic models projected a 1–29% cereal price increase in 2050 due to climate change (RCP 6.0), which would impact consumers globally through higher food prices, although its regional effects will vary. Low-income consumers are particularly at risk, with models projecting increases of 1183 million additional people at risk of hunger across the SSPs compared to a no climate change scenario (IPCC[342], 2020).

In synthesis, World Bank[343] (2009) projections mention that, without the CO_2 fertilisation effect, climate change will reduce the mean yields for 11 major global crops – millet, field pea, sugar beet, sweet potato, wheat, rice, maize, soybean, groundnut, sunflower and rapeseed – by 15% in Sub-Saharan Africa, 11% in Middle East and North Africa, 18% in South Asia, and 6% in Latin America and the Caribbean by 2046–2055, compared to 1996–2005. A separate meta-analysis suggested a similar reduction in yields in Africa and South Asia due to climate change by 2050 (Knox[344] et al., 2012). Schlenker[345] and Lobell (2010) estimated that in sub-Saharan Africa, crop production may be reduced by 17–22% due to climate change by 2050. At the local level, climate change bearings on crop yields vary by location. Negative impacts of climate change on agricultural productivity contribute to higher food prices.

The imbalance between supply and demand for agricultural products is projected to increase agrarian prices in the range of 31% for rice to 100% for maize by 2050 (Nelson[346] et al., 2010), and cereal prices in the range between a 32% increase and a 16% decrease by 2030 (Hertel[347] et al., 2010). In southern European Russia, it is projected that the yields of grain crops will decline by 5-10 % by 2050 due to the higher intensity and coverage of droughts (Ivanov[348] et al., 2018). In socio-economic terms, the implications of the rise in the food price index are pretty worrying. The WB estimates that every one percentage point increase in the food sector puts ten million more people into extreme poverty.

The food system finds itself in a unique situation: it suffers the effects of climate change, which has CO_2 as one of its main drivers and, at the same time, is responsible for the significant emission of 21-37% of CO_2, mainly due to how agricultural production is practised and land use, as well as the current storage patterns, transportation, packaging, processing, retail, and consumption.

---

[342] IPCC (2020) – Climate Change and Land. An IPCC Special Report on climate change, desertification, land degradation, sustainable management, food security and green gas fluxes in terrestrial ecosystems. Chapter 5: 437-550.

[343] World Bank (2009) - *Guidance notes mainstreaming adaptation to climate change in agriculture and natural resources management projects*. Note 7: evaluate adaptation via economic analysis [available at http://climatechange.worldbank.org/content/note-7-evaluate-adaptation-economic-analysis]

[344] Knox, J., Hess, T., Daccache, A., and T. Wheeler, T. (2012) - Climate change impacts on crop productivity in Africa and South Asia. *Environ. Res. Lett.*, 7, 34032,

[345] Schlenker, W., and Lobell, D.B. (2010) - Robust negative impacts of climate change on African agriculture. *Environ. Res. Lett.*, 5, 14010, [doi:10.1088/1748- 9326/5/1/014010].

[346] Nelson, G.C. et al., (2010) - *Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options*. International Food Policy Research Institute, Washington, DC, USA. 131 pp.

[347] Hertel, T., _Burk, M.B., and Lobell, D.B. (2010) - The poverty implications of climate-induced crop yield changes by 2030. *Glob Environ. Chang.* 20: 577-585

[348] Ivanov, A.L. et al., (2018) - National report global climate and soil cover of Russia: Assessment of risks and environmental and economic consequences of land degradation. Adaptive systems and technologies of environmental management (agriculture and forestry). In: Russion: NATSIONAL'N. Moscow, Russia, 357 pp.

This amount is divided into the following parts: 9-14% coming from agricultural and livestock activities within the property and 5-14% coming from land use and changes in land use, including deforestation and degradation of peatlands; 5-10% comes from supply chain activities (includes GHG emissions from food loss and waste).

Within the food system, during the period 2007 - 2016, the major sources of emissions from the supply side were agricultural production, with crop and livestock activities within the farm gate generating respectively 42 $TgCH_4$ yr^{-1} and 2.5 TgN_2O yr^{-1} and CO_2 emissions linked to relevant land-use change dynamics such as deforestation and peatland degradation, generating 2.5 $GtCO_2$ yr^{-1}. Using 100-year Global Warming Potential (GWP) values (no climate feedback) from the IPCC AR5, this implies that total GHG emissions from agriculture were 1.4 $GtCO_2$-eq yr^{-1}, increasing to 2.9 $GtCO_2$-eq yr^{-1} including relevant land use. Without intervention, these are likely to increase by about 30 to 40% by 2050, due to increasing demand based on population and income growth and dietary change. It must be realized, however, that the ability to estimate climate change yield impacts on world and regional food supply, demand and trade is still surrounded by large uncertainties regarding the magnitude and spatial characteristics of climate change, the range and efficiency of adaptation and mitigation possibilities as well the long-term aspects of technological development and the degree of its adoption. We also cannot forget there may be social and economic and adaptative constrains that may not necessarily result in sustainable production over long timeframes.

Considering the already available knowledge on the vulnerability of agriculture in the face of very likely trends in climate change, research institutions have a high responsibility in responding to: i) what are the heat-tolerance limits of currently grown crops and of alternative crops and varieties? ii) What agronomic methods best moderate the thermal regime affecting crop growth? iii) What policies are being devised and enabled to facilitate the adjustment of agriculture to the likelihood of environmental change?

5.10.2 - Predictable impacts on livestock and pastoral systems

Available data for the world's large areas shows that climate change affects livestock production in multiple ways, both directly and indirectly. The most critical impacts are experienced in animal productivity, yields of forages and feed crops, animal health and biodiversity.

The importance and magnitude of these shocks must not be overlooked, as climate change has a direct effect on food systems, and the extent and dimension of the changes likely to occur in livestock systems due to this. In industrialized countries, livestock systems are, for the most part, decoupled from the production of forage crops, which directly impacts food security, as large tracts of intensive agricultural land are diverted to produce food for feed production. In developing countries and Mediterranean livestock systems, less intensive feeding systems intertwined with cropping systems are more prevalent on the southern rim. In a study for the FAO, Seré[349] and Steinfeld (1996) distinguish 11 livestock-crop systems based on the combination of several factors, including agroecological zones, grassland or landless systems, crop-livestock

[349] Seré, C. and Steinfeld, H. (1996) - *World livestock production systems: current status, issues and trends*. FAO Animal Production and Health Paper 127, FAO, Rome, Italy, 49 p.

or livestock-only systems and – for the crop-livestock systems – rainfed or irrigated systems. Each of these systems will interact differently with climate change.

The effects of climate change on fodder crops will be like the effects on any crop, as mentioned above. In pastures, higher temperature increases the lignification of plant tissues and, therefore, reduces grasses' digestibility. Pasture production will likely increase in the humid temperate grasslands but probably decrease in arid and semi-arid regions (Easterling et al., 2007). However, grassland ecosystems, particularly animal response to availability and nutritional value changes, are very complex, complicating livestock adaptation to climate change (Thornton[350] et al., 2009). To a lesser extent, impacts on feed crops, forages, and grasslands have also been quantified despite uncertainties resulting from complex interactions between climatic factors, mainly temperatures and CO_2 concentrations. Stress on water resources is also likely to affect livestock production, but the extent of this impact of reduced water availability on livestock is unclear.

Livestock's vulnerability depends first on their exposure to climate shocks: duration, frequency and severity, stock location and relevant assets such as feedstock, housing, water points, etc. It also depends on their sensitivity: type of breed, housing or feeding system, the status of animal health and the importance of livestock to the household regarding food security and livelihoods (ICEM, 2013). In addition, several factors increase livestock's vulnerability to climate change, especially in semi-arid and arid regions. They include rangeland degradation, fragmentation of grazing area, changes in land tenure, conflicts and insecure access to land and finally, markets (e.g. crop residues and by-products for feed and animal products).

Despite uncertainties about the intensity of these adverse effects, it was found that increased temperatures and reduced precipitation have direct negative impacts on yields. Records during drought events can reveal significant drops in forage production, such as the 60 per cent deficit of green fodder during the 2003 summer in France. According to an industry survey, dairy cows in the hotter Southern European countries spent more than half of the day under heat stress, resulting in an estimated milk loss of up to 5.5 kg/cow/day (FeedInfo[351], 2015). In Italy, Crescio[352] *et al.* (2010) reported that high temperatures and air humidity could lead to a 60 percent increase in cattle mortality.

But climate change can also affect fodder quality through shifts from C3 to C4 plants and increased shrub cover, an increase in lignification as well as plant secondary metabolites such as tannins, alkaloids, saponins, among others, in plant tissues under higher temperatures (Wilson[353], Deinum and Engels, 1991). An increase in fungi and mould infestation and its prevalence in feed resources under increased variability in precipitation could also impact feed and food safety.

The temperature increase will likely alter heat exchange between animals and the environment, potentially affecting feed intake, mortality, growth, reproduction, and production. It is also known that high temperatures put a ceiling on dairy milk yield irrespective of feed intake

[350] Thornton, P.K., van de Steeg, J., Notenbaert, A. and Herrero, M. (2009) - The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems*, 101: 113-127

[351] FeedInfo. (2015) - *Lallemand animal nutrition warns of heat stress in cows all over Europe* [available at: http://www.feedinfo.com/console/PageViewer.aspx?page=5050311&str=lallemand].

[352] Crescio, M.I., Forastiere, F., Maurella, C., Ingravalle, F. & Ru, G. - (2010) – Heat-related mortality in dairy cattle: a case crossover study. *Preventive Veterinary Medicine*, 97(3): 191-197

[353] Wilson, J., Deinum, B. & Engels, F. (1991) - Temperature effects on anatomy and digestibility of leaf and stem of tropical and temperate forage species. *Netherlands Journal of Agricultural Science*, 39: 31–48.

(Parsons[354] et al., 2001). As opposed to crops, livestock much better withstand extreme weather events such as heat and drought. However, critical temperature thresholds for livestock remain poorly known (Thornton et al., 2009).

The impact of climate change on infectious livestock diseases depends on the ecosystem affected, the type of land use change, disease specific transmission dynamics and the susceptibility of the livestock population at risk and are consequently very complex. However, FAO[355] (2015) documented, especially for vector-borne diseases, rising temperatures increasing winter survival of vectors and pathogens. Diseases such as West Nile virus and schistosomiasis and bluetongue or Lyme are projected to expand into new areas.

This author identified the rangeland-based arid/semi-arid and mixed rainfed arid/semi-arid systems in substantial parts of West, East and southern Africa as most at risk from climate change. However, livestock-cropping systems are highly dynamic. Environmental characteristics play a significant role in determining their nature and evolution, as do factors such as cultural preferences and access to capital (Delgado[356] et al., 1999).

Population and income growth will considerably increase the demand for livestock products in the coming decades, representing a food revolution (Delgado[357], 2003). Let's consider the energy flow to the herbivores through the green plants' production level; we can see the very low efficiency of the process and the stresses this change in food habits will impose on the environment. In most ecosystems, grazers or browsers do not efficiently harvest plant tissue. Consumption by herbivores varies over a wide range, but it is usually less than 20 % of the green net primary production. Of this amount, roughly 10% is stored as new herbivore tissue, available for the secondary consumer. The other 90% is used either in the maintenance of the herbivore and lost as heat or goes to decomposers as faeces and excretions. Accordingly, about 180 of the 1800 kcal of plant material eaten by herbivores become new animal biomass (Brewer[358], 1994). Increasing meat demand and the low conversion factor will entail land-use intensification and shifts in livestock and feed production locations. These driving forces are likely to exert more significant pressures on livestock production systems than climate change itself, giving rise to simplistic narratives and widely disseminated claims that "meat and milk are bad for the environment" without a systemic analysis that considers the diversity of global livestock production systems and their different impacts on landscapes and livelihoods.

When analysing the impacts of climate change and the relationships between livestock production systems and their effects on the environment and social systems, it is imperative, as Houzer[359] and Scoones (2021) refer, to consider the integration of contextual factors, such as means of subsistence, nutrition, food security and local agro-ecological conditions. This will

---

[354] Parsons, D.J., Armstrong, A.C., Turnpenny, J.R., Matthews, A.M., Cooper, K. and Clark, J.A. (2001) - Integrated models of livestock systems for climate change studies. 1. Grazing systems. *Global Change Biology*, 7, 93-112

[355] FAO (2015) – Climate Change and Food Security: Risks and Responses. FAO, Rome, 122 pp

[356] Delgado, C., Rosegrant, M., Steinfeld, H., Ehui, S. and Courbois, C. (1999) - Livestock to 2020: the next food revolution. IFPRI Food, Agriculture and the Environment Discussion Paper 28, International Food Policy Research Institute (IFPRI), Washington DC, USA, 72 p.

[357] Delgado, C. (2003). Rising Consumption of Meat and Milk in Developing Countries Has Created a New Food Revolution. *The Journal of Nutrition*, 133(11): 3907-3910

[358] Brewer, Richard (1994) – *The Science of Ecology*. Cengage Learning, 2nd edition, 773 pp.

[359] Houzer, E. and Scoones, I (2021) – Are Livestock Always bad for the Planet? Rethinking the Protein Transition and Climate Change Debate. PASTRES, 80 pp. [pastres.org/livestock-report]

avoid committing to political and behavioural changes to deal with the pressing global challenge of climate change that may cause more harm than good.

5.11 - Foreseeable Mediterranean global impacts on forests

Climate change directly threatens forest ecosystems, people who are dependent on forests (around 1.6 billion people depend on them in whole or part), and society through a reduction in the delivery of products and Forest Ecosystem Services (FES). Forest ecosystems store globally about 80% of the above ground carbon and over 50% of soil organic carbon making, therefore, an important contribution to the regulation of the global carbon balance and to mitigation of climate change. According to FAO[360] (2018) the world's forest stores an estimated 296 Gt of carbon in both above and below-ground biomass (global average of 74 $tyear^{-1}$). Over the past 25 years, due to the conversion of forest lands to agriculture, urbanization, and forest degradation, the forests' carbon stock has decreased by almost 11.1 Gt, equivalent to a reduction of 442 $Mtyear^{-1}$.

Forests, as reserves, sinks, and carbon sources, have become vital issues in global politics, along with the Kyoto Protocol of the Framework Convention on Climate Change, the Bali Action Plan, and the Paris Agreement. Therefore, it is no surprise that climate change and climate variability pose significant challenges for forestry in the coming decades, as they are expected to drastically modify tree-growing conditions. They threaten the supply of a series of crucial goods (wood and non-wood) and environmental services from forests, on which around 1.6 billion people depend in whole or in part. Forests and trees' roles are varied, including, among others, delivering a clean and reliable water supply, protecting against landslides, erosion, and land degradation, providing or enhancing the habitat of aquatic and terrestrial animals, providing a range of products for household use or sale, as well as employment.

Forests support up to 80% of terrestrial biodiversity and play a vital role in safeguarding the climate by naturally sequestering carbon. Yet, at the world level, each year, an average of 13 million hectares of forest disappears, often with devastating impacts on communities and indigenous peoples. The conversion of forests to produce commodities - such as soy, palm oil, beef and paper—accounts for roughly half of global deforestation. Infrastructure, urban expansion, energy, mining and fuel wood collection also contribute to varying degrees.

Despite forest ecosystems being inherently dynamic, the speed of predicted changes is likely to far exceed the natural capacity of many forest species to adapt. In addition, extreme climatic events and climate-related disasters may overwhelm countries' capacities to respond effectively. Therefore, it is no surprise that climate change and climate variability pose significant challenges for forestry in the coming decades, as they are expected to modify tree-growing conditions drastically. It is worth mentioning that Doughty[361] et al. (2023) note that trees are particularly vulnerable to warming extremes because they could quickly exceed their acclimatization limits. They show that above 46.7ºC, the leaves lose their photosynthesis capacity. Today, only 0.01% of

[360] FAO (2015) – Climate change for forest policy-makers – An approach for integrating climate change into national forest policy in support of sustainable forest management. FAO Forestry Paper no. 181. Rome, 68 pp.

[361] Doughty, C.E., Keany, J.M., Wiebe, B.C., Rey-Sanchez, C., Carter, K.R., Middleby, K.B., Cheesman, A.W., Goulden, M.L., et al. (2023) – Tropical Forest are approaching critical temperature thresholds, *Nature* 621:105-111

foliage exceeds this temperature, but in a +4ºC warming model, this figure would increase to 1.4%, a threshold sufficient to cause the death of the entire tree.

Although it is often difficult to separate climate change from other stressors, evidence shows that in various places, climate change is contributing to decreased productivity and dieback of trees from drought and temperature stress, increased wind and water erosion, increased storm damage, increased frequency of forest fires, pest and disease outbreaks, changes in ranges of forest plants and animals, inundation and flood damage (Braatz[362], 2012). Research on global warming effects on forest ecosystems has focused mainly on the physiological level (e.g. Castells[363] et al., 2002) and landscape-level responses (e-g. Peñuelas[364] and Llusià (2003).

Deforestation or afforestation, wherever it occurs, triggers simultaneous warming and cooling of the surface and the atmosphere via changes in its various characteristics (Strengers[365] et al., 2010; Bonan[366], 2008; Rodrigues[367] et al., 2021). Following deforestation, warming results from: (i) the release of CO_2 and other GHGs in the atmosphere (biogeochemical impact) and subsequent increase in incoming infrared radiation at the soil surface (greenhouse effect), (ii) a decrease in the total loss of energy through turbulent fluxes (latent and sensible heat fluxes) resulting from reduced surface roughness; (iii) an increased incoming of solar radiation following reduced cloudiness that often (but not always) accompanies the decreased total evapotranspiration. Cooling occurs in response to: (i) increased surface albedo that reduces the amount of absorbed solar radiation, (ii) reduced incoming infrared radiation triggered by the decreased evapotranspiration and subsequent decrease in atmospheric water vapour. Deforestation and afforestation also alter rainfall and winds (horizontal and vertical).

The literature discussing the effects of afforestation on climate is more limited than for deforestation, but they reveal a similar climatic response with opposite signs. Specific model-based deforestation studies have been carried out for West Africa (Boone[368] et al., 2016; Hartley[369]

---

362 Braatz, S. 2012. Building resilience for adaptation to climate change through sustainable forest management. *In:* A. Meybeck, J. Lankoski, S. Redfern, N. Azzu & V. Gitz. *Building resilience for adaptation to climate change in the agriculture sector*. Proceedings of a joint FAO/OECD Workshop. Rome, FAO.

363 Castells, E., Roumet, C., Peñuelas, J., Roy, J. (2002) – Intraspecific variability of phenolic concentrations and their responses to elevated CO_2 in two Mediterranean perennial grasses. *Environ. Exp. Bot*. 47: 205-216

364 Peñuelas, J. and Llusià, J. (2003) – BVOCs: plant defense against climate warming? *Trends Plant Sci*. 8: 105-109

365 Strengers, B.J. et al. (2010) - Assessing 20th century climate-vegetation feedback of land-use change and natural vegetation dynamics in a fully coupled vegetation-climate model. *Int. J. Climatol.*, **3**0: 2055–2065, [doi:10.1002/joc.2132].

366 Bonan, G.B. (2008) - Forests and climate change: Forcing's, feedback, and the climate benefits of forests. *Science*, 320, 1444–1449, [doi:10.1126/ science.1155121].

367 Rodrigues, A., Sardinha, R. A., Pita, G. (2021) – *Fundamental Principles of Environmental Physics*. Springer, 372 pp. [https: doi.org/10.1007/978-3-030-69025-0].

368 Boone, Aaron A., Xue, Y., de Sales, F., Comer, R.E., Hagos, S., Mahanama, S. et al. (2016) – The regional impacto of Land-Use Land-cover Change (LULCC) over West Africa from an ensemble of global climate models under the auspices of the WAMME2 project. *Clim. Dyn.*, 47: 3547-3573 [doi:10.1007/s00382-016-3252-y]

369 Hartley, I.P., Garnett, M.H., Sommerkon, M., Hopkins, D. W., et al. (2012) - A potential loss of carbon associated with greater plant growth in the European Arctic. *Nat. Clim. Chang*., 2: 875–879, [doi:10.1038/nclimate1575].

et al., 2016; Klein[370] et al., 2017), Southern America (Wu[371] et al., 2017; Spracklen[372] and Garcia-Carreras, 2015) and Southeast Asia (Tölle[373] et al., 2017). All found decreases in evapotranspiration following deforestation, resulting in surface warming, despite the competing effect from increased surface albedo. Changes in thermal gradients between deforested and adjacent regions, between land and ocean, affect horizontal surface winds and thus modify the areas where rain falls. An increase in the land-sea thermal contrast has been found in many studies as surface friction is reduced by deforestation, thus increasing the monsoon flow in Africa and South America (Wu[374] et al., 2017).

The expected continuation of the current increase in aridity, due to reduced precipitation but also warming and heat events, is likely to be among the most critical threats to Mediterranean land ecosystems (Gouveia[375] et al. 2017; Santonja[376] et al. 2017; Williams[377] et al. 2013). Under an optimistic climate scenario (global temperatures below +1.5°C to +2°C above preindustrial values), western Mediterranean forests may largely survive under future climate conditions in most locations, except for some sites dominated by conifers. With higher warming and a significant reduction in precipitation with important consequences in photosynthesis, forests will suffer substantial reductions in growth and survival (Gea-Izquierdo[378] et al. 2017) reducing its beneficial effect as a carbon sink.

Although the magnitude of changes and variability of precipitation is difficult to predict, it is foreseeable for the Mediterranean region the decrease in rainfall in summer and autumn and the increase in winter, resulting in higher intensity precipitation events which increase erosion, reduction of soil moisture and an overall decrease in water availability due to increased evapotranspiration. The changes in the rainfall distribution patterns may have a more substantial effect on forest growth than the decrease in precipitation because trees are adapted to grow within certain limits of a given climate and water regime. Although forest stands show some plasticity to cope with unstable conditions, growth and vitality are expected to suffer with changes in the timing and duration of water stress.

---

[370] Klein, C., Bliefernicht, J, Heinzeller, D., Gessner, U., Gessner, U., Klein, I. & Kunstmann, H. (2017) - Feedback of observed interannual vegetation change: A regional climate model analysis for the West African monsoon. *Clim. Dyn*. 48: 2837–2858, [doi:10.1007/s00382-016-3237-x].

[371] Wu, M., Schurgers, G., Ahlström, A., Rummukainen; M., Miller, P.A. et al., (2017) - Impacts of land use on climate and ecosystem productivity over the Amazon and the South American continent. *Environ. Res. Lett.*, 12, 054016, [doi:10.1088/1748-9326/aa6fd6]

[372] Spracklen, D.V., and Garcia-Carreras, L. (2015) - The impact of Amazonian deforestation on Amazon Basin rainfall. *Geophys. Res. Lett.*, 42: 9546-9552, [doi:10.1002/2015GL066063].

[373] Tölle, M.H., Engler, S. and Panitz, H.J. (2017) - Impact of abrupt land cover changes by tropical deforestation on Southeast Asian climate and agriculture. *J. Clim.*, 30: 2587-2600 [doi:10.1175/JCLI-D-16-0131.1].

[374] Wu, M., Schurgers, G., Ahlström, A., Rummukainen, M., Miller, P.A., Smith, B., May, W., (2017) -Impacts of land use on climate and ecosystem productivity over the Amazon and the South American continent. *Environ. Res. Lett.*, 12, 054016.

[375] Gouveia, C.M., Trigo, R.M., Beguería, S. & Vicente-Serrano, S.M. (2017) - Drought impacts on vegetation activity in the Mediterranean region: An assessment using remote sensing data and multi-scale drought indicators. *Global and Planetary Change, 151*: 15-27

[376] Santonja, M., Fernandez, C., Proffit, M., Gers, C., Gauquelin, T., Reiter, I.M., Cramer, W. & Baldy, V. (2017) - Plant litter mixture partly mitigates the negative effects of extended drought on soil communities and litter decomposition in a Mediterranean oak forest. *Journal of Ecology, 105*(3): 801-815.

[377] Williams, A.P., Allen, C.D., Macalady, A.K., Griffin, D., Woodhouse, C.A., Meko, D.M., et al. (2013) - Temperature as a potent driver of regional forest drought stress and tree mortality. *Nature Climate Change, 3*(3): 292-297.

[378] Gea-Izquierdo, G., Nicault, A., Battipaglia, G., Dorado-Liñán, I., Gutiérrez, E., Ribas, M. & Guiot, J. (2017) - Risky future for Mediterranean forests unless they undergo extreme carbon fertilization. *Global Change Biology, 23*(7): 2915-2927

Available data suggest that Western Mediterranean forests are vulnerable to a climate warmer than +2°C unless trees develop a strong fertilization response to rising atmospheric CO_2, and provided sites are not nutrient-constrained and of water limitation. Overall, the difference between 1.5°C and 2°C warming for terrestrial ecosystems in the Mediterranean region is highly significant (Guiot & Cramer[379], 2016). It is considered that unprecedented biogeographical changes in the last 10,000 years can only be avoided if global warming is limited to 1.5 °C. If warming reaches 2°C, a significant decrease (12-15%) in the region's capacity to support Mediterranean ecosystems is expected.

According to the Global Forest Resources Assessment Programme (FAO, 2015), the combined forest area of the Mediterranean countries represents approximately 2 per cent of the world's total forest area. Overall, forest area in the Mediterranean countries increased from 68 million hectares in 1990 to 82 million ha in 2015, representing an increase of 0.72 % per year over 25 years. This moderate upward trend has been accompanied by the rise in growing biomass stock that increased in that time frame from 6.3 billion m3 in 1990 to 9.2 billion m3 in 2015. Still, the importance of Mediterranean forests to global forestry goals is far greater than this figure alone suggests. Because of the rich biodiversity in the Mediterranean forests' basin, the region is one of the world's main hotspots of climate change. Considering that 7.3 per cent of the human population lives in Mediterranean countries (World Bank, 2015), the Mediterranean region is critical for achieving the global objectives set for forests, far beyond its primary objective as a supplier of wood products.

In addition to the direct and indirect benefits that forests generate, an essential role is to be a carbon sink. Trees act as carbon sinks when, through photosynthesis, they absorb CO_2 from the atmosphere, releasing oxygen but retaining carbon. Carbon is fixed mainly in wood as lignin and cellulose without, forgetting, however, that soils and undergrowth undercover also contain substantial amounts of fixed carbon (Nilson[380] and Schopfhauser, 1995).

The key to appreciating the significant contributions of forests and the forest-based sector is the perspective of an integrated and circular bioeconomy. CO_2 is substantially removed from the atmosphere and stored in growing forests. The carbon eventually circulates back into the atmosphere to close the loop. Part of this carbon is held in various forest products before re-entering the natural biogenic carbon cycle for a longer or shorter period. Because under sustainable management, they absorb more carbon than they release, forest products have a shallow climate footprint, and they reduce demand for products and energy based on fossil fuels.

Several studies show that the ability of a forest to sequester atmospheric carbon depends on its composition and density, genetic characteristics of the trees and plants, structure of the stand, and climatic and edaphic factors. Age is another crucial factor. Carbon sequestration and organic carbon accumulation in residue and soil reservoirs change as the stand matures or decays or whenever natural or man-made disturbances occur. Consequently, the stage of development of a particular forest stand is one of the crucial factors affecting its structure, composition, and cumulative biomass volume, thereby also affecting carbon dynamics; hence, species selection is significant in the plantations and on the possibilities to be taken in CO_2 mitigation and adaptation strategies. Several studies have also proved that converting forest land or short rotations

---

379 Guiot, J. & Cramer, W. (2016) - Climate change: The 2015 Paris Agreement thresholds and Mediterranean basin ecosystems. *Science, 354*: 465-468

380 Nilson, S. and Schopfhauser, W. (1995) – The Carbon Sequestration Potential of a Global Afforestation Program. *Climatic Change*, 30: 267-293.

plantations to pasture will decrease carbon storage (FAO[381], 2013; Kaul[382] et al., 2010; Berthrong[383] et al, 2012).

Studies developed since 2002 within the Carboeurope European Project have enabled the continuous quantification of atmospheric carbon and water vapour flows in various vegetation covers and demonstrates the temporal interaction between the respective balances. The results obtained for Portugal (Rodrigues[384] and Oliveira, 2006) showed a strong interaction, in annual terms, between atmospheric carbon fluxes and precipitation, which are reflected in the amount of carbon fixed by the vegetation cover.

Pereira[385] et al. (2007 analysing the effect of drought on three Mediterranean ecosystems in southern Portugal during an experimental period (2003-2006), found that the sink capacity for the carbon of either the coppiced eucalyptus plantation (with a sequestration capability of -861 and -399 g C m^{-2} $year^{-1}$) or oak woodland (with a sequestration capacity of -140 and -28 g C $m^{-2}year^{-1}$) and grassland dominated by herbaceous annuals (-190 and +49 g C $m^{-2}year^{-1}$) was significantly restricted by the severe droughts of the hydrologic year of 2004-2005. Data showed that eucalyptus plantations had higher CO_2 sequestration capability than oak woodland or grass. However, more precise conclusions on the assessment of the size of the carbon pool in a plantation require the analysis of the whole ecosystem for more extended periods and long-term trends of soil organic carbon (SOC) tenures and other ecological parameters and processes of primary productions in the terrestrial carbon cycle, as referred among other researchers by Mollicone[386] et al. (2003).

Concerning the fertilizing effect for crops, as already mentioned, it was observed that the increase in atmospheric CO_2 concentration also influences the photosynthesis of forest plants, consistently increasing the efficiency of water use by the plants, increasing the photosynthetic capacity and favouring trees' growth, which varies with site nitrogen availability, the plant, and the species. However, the growth rate of trees may not increase proportionately with increasing photosynthesis due to other limiting factors such as nutrient and water availability. Indeed, droughts reduce gross primary production and ecosystem respiration, contributing to most interannual variability in terrestrial carbon sequestration.

The higher atmospheric CO_2 concentration (increase from 280 ppm in the pre-industrial age to 400 ppm at present, Kennedy[387] 2015), is not expected to lead to an increase in carbon assimilation by natural vegetation in the Mediterranean, mainly because of the impact of drought

381 FAO (2013) – Forestry plan of Uruguay. *Unasylva*, Vol. 2, nº 3 Retrieved:2021/12/25 http://www.fao.org/docrep/x5344e/x5344e05.htm]

382 Kaul, M., Mohren, G. M. J. & Dadhwal V. K. (2010) - Carbon storage and sequestration potential of selected tree species in India. *Mitig. Adapt. Strateg. Glob. Change* 15, 489-510.

383 Berthrong, S.T., Piñeiro, G., Jobbágy, E.G. & Jackson, R.B. (2012) - Soil C and N changes with afforestation of grasslands across gradients of precipitation and plantation age. *Ecological Applications* 22:76–86.

384 Rodrigues, Abel e Oliveira, H. (2006) – Sequestro de carbono. Tendências Globais e Perspetivas do Sector Florestal Português. *Ingenium*, II Série, 92:68-71.

385 Pereira, J.S., Mateus, J.A., Aires, L.M., Pita, G., David, J.S., Andrade, V., Banza, J., David, T.S., Paço, T.A., Rodrigues, A. (2007) – Net ecosystem carbon exchange in three contrasting Mediterranean ecosystems – the effect of drought. *Biogeosciences*, 4: 791-802. [https://doi.org/10.5194/bg-4-791-2007]

386 Mollicone, D., Metteucci, G., Köble, R., Masci, A., Chiesi, M., Smiths, P.C. (2003) – A Model-Based Approach for Estimation of Carbon Sinks in European Forests, 179-206. In: Ecological Studies, Vol. 163, R. Valentini (ed.) *Fluxes in Carbon, Water and Energy of European Forests*. Springer-Varlag Berlin Heidelberg 2003.

387 Kennedy, C. (2015). 2014 State of the Climate: Carbon Dioxide. NOAA-www.climatM.gov/

to metabolic limitation to photosynthesis (Saxe[388] and Health, 1998), limitations in water availability and nutrients. Thus, sclerophyllous vegetation that dominates the Mediterranean will not be favoured by CO_2 changes, while thermophilus species will have to deal with better climatic conditions mainly because of the warmer winters.

In general, the net increment of European forests has increased in the second half of the twentieth century (Spiecker[389], et al., 1996). Various authors found at least four different trends contributing to the increase in net forest increment in Europe: i) intensive silviculture and silvicultural expertise widely used and maintenance of a large growing stock during all phases of stand rotation; ii) expansion of forest land; iii) reduced grazing pressures; and iv) increased rates of nitrogen deposition. It follows that the forest vegetation carbon pool is expanding.

The Mediterranean species are established in temperature zones near their optimum photosynthesis values (Wertin[390] et al., 2011). An increase in temperature (near or beyond its critical values) combined with low water availability, especially in summer, is expected to lead to photosynthesis decline, reduction in CO2 assimilation and stomatal conductance, cell dehydration and necrosis. There are, however, species tolerant to high temperatures with specific morphological characteristics (small thick or trichome-covered leaves, small leaf angles with the shoot, etc.) and adaptation strategies (such as completing biological stages before the drought initiation, intraspecific variability, phenotypic plasticity, local adaptation. Bussotti[391] et al., (2014) presented an interesting review of the adaptation mechanisms of Mediterranean heat-tolerant species to drought. Also, they mentioned extensively reported tree dieback events in southern Europe and Mediterranean regions and the suffering of sclerophyllous Mediterranean vegetation due to severe drought events.

Significant disruptions of ecosystems from disturbances such as fires, droughts and pathogens are expected to increase (IPCC[392], 2001). Generally, pathogens and trees are balanced, and the pathogen's virulence is just enough to kill weak trees. Still, those growing at their full potential can complete their life cycle without severe interference from the pathogen. As unfavourable environmental conditions weaken trees, more significant proportions will become susceptible to pathogens (David[393] et al., 1992; Cabral[394] et al., 1993; Dios[395] et al., 2006). As Dios et al. (2007) mentioned, this will have a twofold effect on the pathosystem. First, many trees will die, reducing the standing biomass. Secondly, the pathogen population will be built up to the point of

---

[388] Saxe, H., Ellsworth, D.S. and Heath, J. (1998) - Tree and forest functioning in an enriched CO_2 atmosphere. *New Phytologist* 139: 395–436.

[389] Spiecker, H., Mielikäinen, K., Köhl, M. and Skovgaard, J. (eds) (1996) – Growth Trends in European Forests. European Forest Institute Research Report no. 5. Berlin/Heidelberg/New York: Springer-Verlag, 372 pp.

[390] Wertin, T.M., McGuire, M.A. and Teskey, R.O. (2011) - Higher growth temperatures decreased net carbon assimilation and biomass accumulation of northern red oak seedlings near the southern limit of species range. *Tree Physiology* 31: 1277–1288.

[391] Bussotti, F., Ferrini, F., Pollastrini, M. and Fini, A. (2014). The challenge of Mediterranean sclerophyllous vegetation under climate change: From acclimation to adaptation. *Environmental and Experimental Botany* 103: 80–98.

[392] IPCC (2001) – Climate Change 2001: The scientific basis. Cambridge, University Press, Cambridge. 886 pp.

[393] David, T.S., Cabral, M.T. e Sardinha, R.M.A. (1992) - Mortalidade dos Sobreiros e a Seca. *Finisterra*, Vol. XXVII, nº 53-54: 17-24.

[394] Cabral, M.T., Lopes, F. e Sardinha, R.M.A. (1993) - Determinação das Causas de Morte do Sobreiro nos Concelhos de Santiago do Cacém, Grândola e Sines. Relatório Síntese. *Silva Lusitana* Ano I, Vol. I, Nº 1: 7-24

[395] Dios, V.R. de Fischer, C., Colina, C. (2007) – Climate change effects on Mediterranean forests and preventive measures. *New Forests* 33: 29-40

threatening trees that perhaps could resist a light attack but not a heavy infestation. These consequences will probably be more intense at the edges of the species' natural distribution.

The Mediterranean mountains are considered highly vulnerable to climate change. Numerous studies foresee that warming, decreased precipitation, and interannual variability will be more intense than in other mountains with higher species losses (Bakkenes[396]et al., 2006). Ruiz-Labourdette[397] et al. (2013) forecast for the Mediterranean mountains' vegetation that xerophilous vegetation will considerably increase and dominate low mountain areas, and perennial sclerophyllous species will also increase, while moderate tolerant to water availability vegetation will notably decrease. At higher altitudes, vegetation will upshift, the semiarid forests will expand, the broadleaf forest area will reduce, and the cold gymnosperm forest will radically reduce their expansion ranges.

If global temperatures are kept below 2 ºC above preindustrial values at the end of the 21st century, most Mediterranean forests could resist warming (except for some coniferous sites). However, higher temperatures and rainfall reduction might reduce the effects of CO2 fertilization and undermine forest growth and survival. In contrast, most western Mediterranean forests are vulnerable to a climate warmer than 2 ºC above preindustrial values if no unexpected physiological adaptation occurs (Gea-Izqierdo et al., 2017). This change would imply the loss of many resources drawn from forests and a lost carbon sink capacity, especially during drought (Rambal[398] et al., 2014; Muñoz-Rojas[399], et.al., 2015).

Climate change is ongoing and recent global temperatures are already more than one degree above the pre-industrial levels, with some regional differences (stronger warming especially in higher latitudes). Besides the warming trend characterizing the current climate change, extreme events have been amplified with extended periods of hot spells and drought. For example, the years 2017 to 2020 were exceptionally warm and in large parts of Europe it was also particularly dry. Consequently, in recent years, Mediterranean and European forests have been affected by severe droughts, widespread wildfires, a series of windstorms, rapidly expanding bark beetle infestations and several other pest and disease outbreaks. Evidence is increasing that these events have become much more frequent and more threatening because of climate change (Seidl[400] et al., 2017).

These changes constitute a major challenge for future forest management. Climate change and associated extreme events are already affecting the growth and stability of European forests. While the analysis of forest growth changes in the late 20th century showed nitrogen deposition as a major explanatory factor with only a limited contribution of CO2 fertilization and climate

---

396 Bakkenes, M., Eickhout, B. and Alkemade, R. (2006) - Impacts of different climate stabilization scenarios on plant species in Europe. *Glob. Environ. Change* 16: 19–28.

397 Ruiz-Labourdette, D., Fe Schmitz, M. and Pineda, F.D. (2013) - Changes in tree species composition in

Mediterranean mountains under climate change: Indicators for conservation planning. *Ecological Indicators* 24: 310–323.

398 Rambal, S., Lempereur, M., Limousin, J.M., Martin-StPaul, NK., Ourcival, JM., and J. Rodríguez-Calcerrada, J. (2014) – How drought severely constrains gross primary production (GPP) and its partitioning among carbon pools in a Quercus ilex coppice? *Biogeosciences*, 11: 6855-6869

399 Muñoz-Rojas M., Doro, L., Ledda, L., Francaviglia, R. (2015) – Application of CarboSoil model to predict the effects of climate change on soil organic carbon stocks in agr-silvo-pastoral Mediterranean management systems. *Agriculture, Ecosystems & Environment*, 202: 8-16

400 Seidl, R., Albrich, K., Erb, K., Formayer, H., Leidinger, D., Leitinger, G., Tappeiner, U., Tasser, E., Rammer, W. (2019) - What drives the future supply of regulating ecosystem services in a mountain forest landscape? *Forest Ecology and Management* 445: 37-47.

change (Kahle[401] et al., 2008), empirical growth trend analysis extending to 2010 showed that climate warming and extended growing season explained a substantial part of the growth enhancement observed around the year 2000 (Pretzsch[402] et al., 2014). The observed increase in forest productivity in high latitudes (Henttonen[403] et al., 2017) and higher altitudes of mountainous regions (Sedmáková[404] et al., 2019) was due to climate warming. Dendrochronological studies indicate that tree growth responses at low elevations differed from higher elevations, and the growth of spruce and beech decreased from 1991–2012 compared to 1961-1990 in the sub-montane belt (Sedmáková et al., 2019). Trees may suffer from drought stress when temperature increases occur in combination with extended periods of below-average precipitation. Drought-induced growth declines have increasingly been observed at the dry distribution limits of species, such as in the Wallis in Switzerland and in temperate lowland forests in Belgium (Kint[405] et al., 2012).

Regarding the Mediterranean, an area of intense and ancient settlements and strong human interaction, the landscape is a complex mosaic of alternating semi-natural habitats, the evolution of the forest and its cantonment is more complex. Meadows and pastures represent one of the most widespread land uses in European Mediterranean areas, plains, lowlands, and mountainous areas that can provide forage for grazing animals or hay conservation. Using terraces in mountainous regions allowed the cultivation of olive groves, vineyards and sowing on the slopes. At the same time, its cultivation represented a means of reducing soil erosion, preventing runoff, and increasing water availability (Blondel[406] 2006).

Historically, forest destruction was the first step consequence of human pressure on the natural habitat due to increasing agricultural activity, livestock, and wood exploitation in the Mediterranean Sea trade cycle to cover the needs of the maritime empire. The progressive reduction and increased utilisation of Mediterranean forests accelerated significantly during the 17th and 18th centuries in most regions and was particularly intense in the northern Mediterranean countries. Due to high demands for timber and other non-wood forest products (cork, pitch, etc.), conflicts for using forest resources became prominent, and the need for regulation was more pressing.

Frequently, rulers have tried to preserve the best forests for shipbuilding, often against the will of local populations, while the obligation to replace harvested trees with new plantings became widespread (Williams[407], 2006). However, no regulation would stop the wave of severe deforestation and degradation that expanded across the globe during the late 17th and early 20th

---

[401] Kahle, H.P., Karjalainen, T., Schuck, A., Ågren, G.I., Kellomäki, S., Mellert, K.H., Prietzel, J., Rehfuess, K.E., Spiecker, H., (2008) - Causes and Consequences of Forest Growth Trends in Europe - Results of the RECOGNITION Project, *EFI Research Report.* Brill Leiden, Boston, Köln.

[402] Pretzsch Pretzsch, H., Biber, P., Schütze, G., Uhl, E., Rötzer, T. (2014) - Forest stand growth dynamics in Central Europe have accelerated since 1870. *Nat Commun* 5, 4967.

[403] Henttonen, H.M., Nöjd, P., Mäkinen, H. (2017) Environment-induced growth changes in the Finnish forests during 1971–2010 – An analysis based on National Forest Inventory. *Forest Ecology and Managemen*t 386, 22-36

[404] Sedmáková, D., Sedmák, R., Bosela, M., Ježík, M., Blaženec, M., Hlásny, T., Marušák, R. (2019) - Growth-climate responses indicate shifts in the competitive ability of European beech and Norway spruce under recent climate warming in East-Central Europe. *Dendrochronologia* 54, 37-48.

[405] Kint, V., Aertsen, W., Campioli, M., Vansteenkiste, D., Delcloo, A., Muys, B. (2012) Radial growth change of temperate tree species in response to altered regional climate and air quality in the period 1901-2008. *Climatic Change* 115: 343-363.

[406] Blondel, J. (2006) - The 'design' of Mediterranean landscapes: a millennial story of humans and ecological systems during the historic period. *Human Ecology*, 34(5): 713–729.

[407] Williams, M. (2006) – *Deforesting the Earth. From Prehistory to Global Crisis. An Abridgment*. Chicago (III). The University of Chicago Press.

centuries, accompanying the Industrial Revolution. Until then, unknown demands for feedstock and timber to supply new industries, energy, and material needs for railroad ties and electricity posts grew exponentially. This increase in consumption happened simultaneously with the maximum agricultural expansion, which was necessary to feed a growing population on the eve of the Green Revolution.

The evolution in the eastern Mediterranean was not that dissimilar. However, it is now recognised that forest resources, although heavily used by a large rural population, were primarily preserved until the mid-19th century (Davis[408], 2007).

In the southern Mediterranean, the new colonial powers that took over the Ottoman possessions brought new rules and values. Colonial forest regulations gave the State the right to manage all forests, frequently favouring the needs of the metropolis and upsetting customary arrangements, which led to the destabilisation of secular land tenure. The result was a period of intense deforestation. It is estimated that half of the remaining forests in Morocco, Algeria and Tunisia were deforested under colonial rule.

The Montado/Dehesa System (typical of southern Portugal and Spain) is characterized by low-density tree cover (represented by *Quercus suber* and *Quercus rotundifolia*) combined with crop production or pastoral activities. This system integrates the three main rural activities (forest/cork product harvesting, livestock farming, and agriculture) within a single landscape comprising grass, evergreen shrubs and trees. This system that combines extensive grazing of natural pastures, cereal cultivation and wood products harvest has shown remarkable stability, biodiversity, and sustained productivity over 800 years due to the maintenance of botanically rich mosaic-like herbaceous plant layers. In addition to agricultural production, these complex systems contributed, at the same time, to several ecosystem services, such as the preservation of the environment and its natural resources, securing the sustainability of the system.

Climate change may be implicated in the increasing incidence of oak declines, such as holm oak and cork oak decline due to *Phytophthora cinnamomi* (Phytophthora root rot) in the Iberian Peninsula (Brasier[409]1996; Sanchez[410] et al., 2002). *P. cinnamomi* requires moist soil conditions to proliferate, which is not typical of the cork oak or holm oak habitat. The frequent occurrence of floods in recent decades, combined with less drainage in certain areas or even in regions compacted of soil due to the excess of cattle in watering areas, created favourable conditions for the proliferation of pathogens in these forests. These floods have been followed by drought events that have weakened the trees and made them more susceptible to the pathogen, resulting in higher mortality than ever. Olivera and Colinas (1995) found a general decrease for cork oak in north-eastern Spain associated with a 30-year weather trend of increased warming and dryness. This may be a short-term fluctuation or a long-term trend that will increase with time.

Observations in Portugal indicate an apparent synchronism between prolonged droughts (1943-45; 1975-76; 1980-83) and the abnormal mortality in cork oak stands. Among driving factors of mortality, there was a list of biological agents, including the appearance of new and more virulent parasites, atmospheric pollution, the ageing of the cork oak trees and the cultural practices of the agricultural systems that coexisted with the exploitation of the cork oak, adding

[408] Davis, D.K. (2007) – *Resurrecting the Granary of Rome. Environmental History and French Colonial Expansion in North Africa,* Athens (Ohio), Ohio University Press.

[409] Brasier, C.M. (1996) - *Phytophthora cinnamomi* and oak decline in southern Europe. Environmental constraints including climate change. *Ann For Sci.* 53:347–358

[410] Sánchez, M. E., Caetano, P., Ferraz, J., Trapero, A. (2002) - Phytophthora disease of Quercus ilex in south-western Spain. *Forest Pathol.* 32: 5-8

up the consequences of a long cycle of droughts in which the stress conditions induced pathologies and weakness syndromes leading to the death of the trees.

However, the simple attribution of mortality exclusively to the simple occurrence of outbreaks of biological agents did not seem very sustainable within the scope of the known interactions in the functioning of ecosystems. As Brasier (1996) mentioned, attempts to forecast an interaction of climate change with such ecologically complex and possibly even chaotic sets of processes as oak decline phenomena or pathogen activity must be taken with caution.

Given the apparent multidimensional nature of the factors involved in cork oak mortality, the multidisciplinary research group at the Portuguese National Forestry Station understood that its study should be approached in an integrated manner involving four major blocks, namely: 1) the interface with the social system (cultural systems, evolution of the areas covered and its possible relationship with the retraction of the Montado and its relationships with cultural activities and mortality; 2) the characterization of the physical environment that would form the basis that determines the conditions for growth of the populations and the greater or lesser resilience of the ecosystem to interventions in the ecological system; 3) the dynamics of the ecosystem in order to assess the physiological functions - nutrients and water relations - which are determinants of the greater or lesser susceptibility of the stands to pests, diseases or the degeneration of the trees and their reaction to interventions in the productive system; 4) identification and assessment of populations of pathogens and insects in order to assess the levels of occurrence to infer whether there were plague situations or localized occlusion of disease likely to be quelled by means of traditional combat. The study carried out between 1988 and 1991 indicated an interaction of factors leading to the decline of the forest and showed that these are complex phenomena where it is impossible to isolate a single easily manipulated element (Cabral, et al., 1993).

If it is true that the outbreaks of prolonged drought were accompanied by a more significant occurrence of pests and diseases, the study showed that the events of intense attacks that led to the death of the trees coincided with their poor physiological state, which did not happen in stands or trees in excellent vegetative conditions. It seems legitimate to rule out that pests and diseases were the leading cause of mortality, but rather the combination of the effects of drought and anthropic factors linked to how the Montado is exploited and managed. Leading driving causes were grouped into three types of factors as outlined: i) factors that predispose the ecosystem to decline, ii) factors that trigger ecosystem deterioration, and iii) factors that accelerate ecosystem regression.

The effects of climate change and increased pathogen activity have also been found for other species in the Mediterranean area. So, attacks of *Ceratocysits ulmi* (Dutch-elm disease) and *Hypoxylon mediterraneum* will likely become more active in southern Europe through global warming since high temperatures and dry conditions favour these fungi.

More worrying because of its impact on *Pinus pinaster*, one of the main resinous species of high industrial value in Spain, Portugal, and France, is the case of infestations by *Bursaphelenchus xylophilus* (Pine wilt nematode), which damaged about 2.3 Mm^3 of pine timber in Japan in 1979. This pathogen was found in Portugal for the first time in 1999 (Mota[411] et al., 1999), and the affected populations have remained stable so far. Since this nematode is currently limited by cold temperatures, robust prevention to avoid colonization of new areas is essential because forests

[411] Mota, M.M., Braasch, H., Bravo, M.A., Penas, A.C., Burgermeister, W., Metge, K., Sousa, E (1999) First report of *Bursaphelenchus xylophilus* in Portugal and in Europe. *Nematology* 1:727–734

will become more susceptible to new stress conditions and warming temperatures, and the nematode's potential distribution in Europe will increase.

Estimated drought-induced mortality in several populations of three pine species that co-exist in the NE Iberian Peninsula (Martínez-Vilalta[412] and Piñol, 2002) (*Pinus nigra*, *P. pinaster* and *P. sylvestris*) by *Thaumetopoea pytiocampa* (Pine tent caterpillar) showed that mortality only affected *P. sylvestris* and that there were significant differences between two populations of this species. Although maximum hydraulic conductivity and vulnerability to embolism were almost identical among species and populations, they differed in other aspects of their hydraulic architecture, particularly concerning the hydraulic conductivity per unit of leaf area. It was lower in the most acutely affected *P. sylvestris* population. Lower leaf-specific conductivity causes higher water potential gradients and, hence, higher levels of embolism (if vulnerabilities are alike). The authors suggested that this difference was the leading cause of the observed mortality pattern differences. *P. pinaster* showed higher water-use efficiency (WUE) than the other two species.

P. pinaster is deteriorating very rapidly in places where water stress is precocious and intense, even when climate change is only a weak trend (Allué-Andrade[413] 1995). Irregular weather during spring can create dieback in some species, particularly *Pinus pinea* L. (Umbrella pine) (Allue´-Andrade 1995). Presently, *Pinus nigra* Arnold (Austrian pine), *P. pinea, P. pinaster* and *P. sylvestris* are more damaged than the surrounding understory. Substitution of these species is likely, and *Juniperus thurifera* L. (Spanish juniper), the conifer species least damaged by drought (Montoya, 1995), may replace many conifer species.

The significant drought-induced mortality observed in the study area in Spain (Martínez-Vilalta and Piñol 2002*).* suggests that a drier climate (as predicted by climate change simulations) may endanger several *P. sylvestris* populations in the Mediterranean basin.

In addition to warming affecting the vulnerability of trees to diseases and pests, it induces migrations and displacements of the species, as already mentioned, concerning crops. So, field studies launched in the nineties by Mediterranean forests on the effects of drought on forest structure indicate that present germination and growth conditions for new saplings are different from those existent when the trees from current stands germinated (Lloret[414] and Siscart 1995; Montoya[415] 1995). It was found severe damage in terms of weakened trees, increased susceptibility to pathogens, increased fire hazard and, finally, the death of many populations. These damages were more severe in hardwood than in softwood species, except for *Quercus coccifera* (L.) (Kermes oak) and *Pinus halepensis* (Aleppo pine), where outcomes still appear uncertain (Montoya 1995). Drought sharply decreased *Q. rotundifolia* populations, even when new ramets appeared after drought because these stands consisted of small groups of large, mature trees that probably could not withstand subsequent drought episodes. Acorn production also diminished with drought; therefore, these fluctuations likely affected fauna populations, which are indispensable for seed dispersal. Acorns successful in germination would find less

---

[412] Martínez-Vilalta, J., Piñol, J. (2002) - Drought-induced mortality and hydraulic architecture in pine populations of the NE Iberian Peninsula. For. Ecol. Manag. 161:247–256

[413] Allue´-Andrade JL (1995) - Naturaleza, efectos y amortiguamiento del cambio climático en los bosques españoles. Montes 40:21–28

[414] Lloret F, Siscart D (1995) - Los efectos demográficos de la sequía en poblaciones de encina. Cuadernos de la Sociedad Española de Ciencias Forestales 2:77–81

[415] Montoya R (1995) - Red de seguimiento de daños en los montes. Daños originados por la sequía en 1994. Cuadernos de la Sociedad Española de Ciencias Forestales 2:83–97

dense forests for the establishment, a severe challenge for this species, which requires shade in its early stages (Montoya 1995).

The effect of the severity of the drought seems, however, less serious in the case of *Quercus rotundifolia*, thanks to the strong capacity of this species to access water from deep soil horizons. The study by David[416] et al., (2004), although limited in time (May 1986 - August 1998) and carried out on only one tree, showed that in this species, even with no apparent symptoms of water stress in the tree during the summer drought, transpiration rates showed an upper limit well below the atmospheric evaporation demand. The authors explain that this restriction seems to be the result of the lower hydraulic conductance of the entire plant in the summer. *As the minimum leaf water potential approaches the threshold of summer xylem cavitation, stomatal closure imposes an additional barrier to water flux, preventing catastrophic loss of water-carrying capacity*. However, this area requires a longer study to understand how long and in the face of more intense and prolonged droughts the species is likely to survive.

P. halepensis appears to be a likely substitute for *Q. rotundifolia* in the short term because it is more drought resistant. *However, its populations are also expected to diminish under long-term drought conditions* (Cámara-Obregón[417], 1998; Lloret and Siscart, 1995). Empirical studies show that the decline of *Q. rotundifolia* was more strongly marked in genetically ill-adapted stands, in reforestations and in those managed under productivity criteria (Montoya-Oliver[418],1995). Unfortunately, *Q. rotundifolia*, which was shown to survive drought but subsequently proved more susceptible to beetle attacks, led to the conclusion that the duration of drought events is a critical factor determining the survival of *Q. rotundifolia*.

Another factor that may drastically modify current forests in the European Mediterranean area is the invasions of exotic species. Plant invasions are enhanced by human activities, which contribute to the transport of propagules over an extended range of distances and will become more critical as new climatic conditions develop (Walther[419] et al. 2002). Introduced exotic species will diminish resources available for native plants through competition and affect an ecosystem's fundamental properties. It remains unclear, however, to what extent these invasions will affect whole plant communities.

Although fire has always been a natural element of forest ecology and a primary shaper of the Mediterranean landscape, the increased frequency of drought in recent years has made fires a severe hazard to forests and rural areas, economic and environmental losses and even human casualties (San-Miguel-Ayanz[420] et al., 2013; Bowman[421] et al., 2017).

---

[416] David, T.S., Ferreira, M.I., Cohen, S., Pereira, J.S. and David J. S. (2004) - Constraints on transpiration from an evergreen oak tree in southern Portugal. Agricultural and Forest Meteorology, 122 (3-4): 193-205

[417] Cámara-Obregón A (1998) - Comportamiento y posibles aplicaciones de Pinus halepensis Mill. Em España, frente al cambio climático. Cuadernos de la Sociedad Española de Ciencias Forestales 7:51–60

[418] Montoya-Oliver, J. (2001) - Selvicultura y cambio climático. *Montes* 64:69–74

[419] Walther G-R, Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T.J.C., Fromentin, J-M., Hoegh-Guldberg, O., Bairlein, F. (2002) - Ecological responses to recent climate change. *Nature* 416:389–395

[420] San-Miguel-Ayanz, J., Moreno, J.M., Camia, A. (2013) - Analysis of large fires in European Mediterranean landscapes: Lessons learned and perspectives. *For. Ecol. Manage.* 294: 11-22. [doi: 10.1016/j.foreco.2012.10.050]

[421] Bowman, D.M.J.S., Williamson, G.J., Abatzoglou, J.T., Kolden, C.A., Cochrane, M.A. et al. (2017) - Human exposure and sensitivity to globally extreme wildfire events. *Nat. Ecol. Evol.* 1, 1–6. [doi: 10.1038/s41559-016-0058]

Drought conditions can exacerbate those conditions (Turco[422] et al., 2018), drastically affecting the flood regime due to erosion and the loss of forest stock, costing billions of Euros in direct and indirect damages. Although some forest fires can be provoked or due to recklessness, the leading causes owe to the highly flammable landscape because of a parallel process of homogenization of forest landscapes (abandonment of rural areas and traditional forest uses and thus a growing young forest and shrubland area) and increased "urban" uses of rural space (recreation, transport, vacation, suburbanization), that results to increased fire incidence, severity and civil risk. Combined with a rooted "fire culture", in which people use fire as an agricultural management tool or for recreation, and the cumulative effects of global warming, circumstances created conditions for true firestorms. Consequently, climate change will affect fire regimes if not already affected (Sarris[423] et al. 2014).

Between 2009 and 2018, the Northern Mediterranean suffered an average of more than 56,000 fire incidents, burning more than 875,000 hectares. Roughly 0.6% of the region's total forest area is burnt each year. Since 2000, fires incidents have been especially critical for some countries in southern Europe. For instance, the fire seasons in 2017 and 2018 was severe in many regions of Southern Europe, with large wildfires associated with unusually intense droughts and heatwaves. In Portugal, the year of 2017 was particularly tragic. An extended and extraordinarily intense fire season yielded a record total rural burned area of about 500,000 hectares and more than 120 fatalities (Turco[424] et al., 2019). The summer of 2018 will also be remembered by the deadliest fires ever recorded in Greece, when a series of wildfires close to Athens killed 99 people, the deadliest in Greece history (AghaKouchak[425] et al., 2018).

Although several peer-reviewed scientific literature have led to a shared perception that fires have increased or aggravated in recent years, the quantitative evidence available indicates that fires have decreased in recent decades in this area (Turco et al., 2016). The increased efforts in fire suppression and prevention in countries with an active forest services organization and active forest policy to counter forest fragmentation and reorganization of forest space have certainly played an essential role in driving the general downward trends described for most of the Mediterranean area (Ruffault[426] et al., 2015).

Most concerning is the fact that this phenomenon does not only affect southern Europe: July 2018 fires showed that northern and central Europe are also on the path of new fires due to climate change. The unusually dry summers in these regions have recently caused large fires in countries like Sweden, Germany, Poland and the United Kingdom, historically not used to such forest fires.

The European Forest Fire Information System[427] (EFFIS) recorded, up to May 2019, eleven times more disasters than usual for this time of year, with a 40% increase in the area burnt, more than during the whole of 2018.

---

422 Turco M, Rosa-Cánovas, J.J., Bedía, J., Jerez, S., Montávez, J.P. et al. (2018) - Exacerbated fires in Mediterranean Europe due to anthropogenic warming projected with non-stationary climate-fire models. *Nat. Commun.* 9: 3821. [doi: 10.1038/s41467-018-06358-z]

423 Sarris, D., Christodoulakis, D., Körner, C. (2011) - Impact of recent climatic change on growth of low elevation eastern Mediterranean forest trees. *Clim. Change* 106: 203-223. [doi: 10.1007/s10584-010-9901-y]

424 Turco, M., Jerez, S., Augusto, S., Tarín-Carrasco, P., Ratola, N. Jimènez-Guerreiro, P. & Trigo, Ricardo M. (2019) - Climate drivers of the 2017 devastating fires in Portugal. *Sci. Rep. Nature Research* 9, 13886. 8 pp. [doi: 10.1038/s41598-019-50281-2]

425 AghaKouchak, A., Huning, L.S., Chiang, F., Sadegh, M., Vahedifard, F. et al. (2018) - How do natural hazards cascade to cause disasters? *Nature* 561, 458–460. [doi: 10.1038/d41586-018-06783-6]

426 Ruffault, J., Mouillot, F., Peters, D.P.C. (2015) - How a new fire-suppression policy can abruptly reshape the fire-weather relationship. *Ecosphere* 6, 1–19. [doi: 10.1890/ES15-00182.1]

427 IFFIS European Forest Fire Information System [EFFIS: http://effis.jrc.ec.europa.eu/reports-and-publications/annual-fire-reports]

Despite that, in recent decades, fire management strategies have improved thanks to new technologies and experience, while climate drivers have led to an opposite trend (Turco[428] et al., 2014; Dupire[429] et al., 2017; Fréjaville[430] and Curt, 2017), rural fires affect an average 375,000 hectares pertaining to Mediterranean countries (a total of 500,000 hectares per year in Europe). In 2017, only in the Mediterranean region, nearly 900,000 hectares burned, equivalent to the total area of Cyprus and the highest figure recorded since 1985. These forest areas burnt each year threaten the exceptional biodiversity of the Mediterranean to the extent that should be evaluated in detail: protected areas burned, habitat of interest, destroyed or affected species of interest (such as Herman turtle or cork oak and associated fauna), increased the volume of CO2 released to the atmosphere, impacted on hydrological balances and water quality or caused irreparable losses of fertile land.

Not accounting for the human loss, fires represent losses of about 3 billion euros per year for the whole European continent. In a scenario of increasing greenhouse gas emissions, it is estimated that for 2070-2100, the economic impact of fires in Greece, Spain, France, Italy and Portugal may reach 5 billion euros per year (Hernández[431], 2019). Portugal is by far the Mediterranean country that has suffered the most from forest fires: in the last 30 years, it has faced more fire incidents, with more hectares burned, 35% of the region's fire incidents and 39% of the area affected yearly occur in Portugal. An average of 2.84% of Portugal's forests burn annually (EFFIS).

So far, in Portugal, the analysis of the time series of fires between 1980 and 2017 and of their severity, translated by the value of the burned area (log-transformed), did not reveal a significant multi-decadienal trend (Mann-Kendal test confirmed that was positive but not significant, value $\rho>0.05$). This allows admitting that this abnormal incidence of fires is due more to structural causes of the Portuguese forest and institutional and political insufficiencies than to the seriousness of the impacts of climate change. However, a finer analysis performed by Turco et al. (2019) using two climate indices for summer (June to August): the TX90p index (percentage of days with maximum daily temperature above the 90th percentile) and the Standardized Soil Moisture Index (SSI) (define as soil moisture deficits relative to the climatology), for the same time series, showed that the TX90p is increasing (4 % /decade $r<0.01$ and SSI is decreasing (0.4/decade ρ-value<0.01) i.e. drought conditions are increasing. Turco et al. (2017) explored a direct association between the summer burned area (BA) of high temperature combined with several drought indicators [SPI (Standardize Precipitation Index), SPEI (Standard Precipitation and Evaporation Index) and SSI] developing an empirical regression model to explain fire variations and its correlation.

The authors conclude that the resulting model:

$$log[BA(t)] = 11.26 - 0.32SSI'(t) + 0.45TX90p'(t)$$

was significative (ρ-value<0.01) with a $R^2=0.61$and SSI presenting a better explanation capability.

---

[428] Turco, M., Llasat, M.C., von Hardenberg, J., Provenzale, A. (2014) - Climate change impacts on wildfires in a Mediterranean environment. *Clim. Change* 125, 369–380. [doi: 10.1007/s10584-014-1183-3].

[429] Dupire, S., Curt, T., Bigot, S. (2017) - Spatio-temporal trends in fire weather in the French Alps. *Sci. Total Environ.* 595, 801–817. [doi: 10.1016/j.scitotenv.2017.04.027].

[430] Fréjaville, T., Curt, T. (2017) - Seasonal changes in the human alteration of fire regimes beyond the climate forcing. *Environ. Res. Lett.* 12, 035006. [doi: 10.1088/1748-9326/aa5d23]

[431] Hernádez, Lourdes (2019) – The Mediterranean burns: WWF's Mediterranean proposal for the prevention of rural fires. WWF Report, 30 pp.

Henceforth, high summer temperatures and drought are both significant predictors for BA (Burned Area). The weight values of extreme temperature variable are larger than that of SSI', indicating that for this region, high temperatures seem to drive BA fluctuations more effectively than drought.

The model does not explain 39% of the variation in the burned area (BA), which, until a more comprehensive analysis, does not exclude effects due to policies, structural insufficiencies, and population behavioural variables (e.g. arson, accidental fires due to poor agricultural practices, misuse of fire in leisure activities, etc.).

Despite these adverse fire events, data showed that countries could slow, halt and reverse global forest loss while enhancing food security for all forest areas in Mediterranean countries. Most of the increase in forest area (an increase rate of around 0.72 %/year) is due to the natural regeneration and afforestation of abandoned agricultural land, reflecting the region's solid dynamic character.

Reducing emissions from deforestation, increasing forest restoration, and increasing carbon sequestration will be extremely important in limiting global warming to 2°C. Forests represent one of the most cost-effective climate solutions available today. Action to conserve, sustainably manage and restore forests can contribute to economic growth, poverty alleviation, the environmental rule of law, food security, climate resilience and biodiversity conservation. It can help secure respect for forest-dependent peoples' rights' while promoting their participation and local communities in decision-making strategies.

Paradoxically, although the generic prescription is known and some countries in the Mediterranean are witnessing an increase in forest area, this has not been enough to strengthen sustainable management, both on the northern and southern shores of the Mediterranean. Some analysts (e.g. Arano[432] and Garavaglia, 2016) mention that the absence of viable value chains maintains these young new forests largely unmanaged, vanishing the economic income that could be generated for the region.

The consequences of this phenomenon are multiple and complex. Some are positive since the increase in the forest area, and increasing stock levels can help restore soil fertility after centuries of degradation, mismanagement, and landscape reconstitution. On the negative side, the lack of adequate management at the level of stands and landscape leads to a rapid build-up of fuels and produces forest structures favourable to fire spreads. Increased continuity in the landscape and unfavourable climatic changes may favour the occurrence of mega-fires and associated ecological and societal risks. Developing sustainable and competitive value chains on wood, non-wood products, agroforestry, and ecosystem services has become the cornerstone for protecting and managing the Mediterranean forests, as stated in the Tlemcen Declaration[433] and the Strategic Framework for Mediterranean Forests[434] (SFMF).

In Portugal, severe structural and economic constraints may be one of the leading causes of the lack of small forest owners' response to the anticipated climate changes. Small forest owners depend heavily on credit availability to meet the costs of forest activities and enable organizations

---

[432] Arano, I. Martinez de and Garavalia, V. (2016) – Forests: Facing the Challenges of Global Change, 113-133. In: Zero Waste in the Mediterranean Natural Resources, Food and Knowledge. MediTERRA ed. International Centre for Advanced Mediterranean Agronomic Studies and FAO. Presses of Sciences PO, 409 pp.

[433] Tlemcen Declaration [www.fao.org/forestry/36632-038883494ea162d6695e84f2182b57129f.pdf]

[434] Strategic Framework for Mediterranean Forests SFMF [www.fao.org/forestry/36306-08872a0d33e559c4f5c42304068d43763.pdf]

capable of promoting their aggregation into scaled areas, allowing professional management. They cannot obtain the necessary credits to purchase the inputs required for investment in maintenance, leading to the abandonment of the land, creating, in this way, areas conducive to the accumulation of abandoned biomass vulnerable to the spread of fires. The absence of an incentive policy based on values corresponding to the environmental services provided by the forests does not help to create incentives aimed at implementing effective management measures suitable for the prevention of forest fires.

Part II - The Portuguese agriculture and forest vulnerabilities in the Mediterranean context

6 – Geographic and land occupation profiles

6.1 – The territory, human occupation

Portugal is positioned in the western part of the Iberian Peninsula, bordered by the North Atlantic on the west and south, and Spain on the north and east. Its territory covers about 92 226 km^2 (9.2 million hectares) and comprises three territorial areas: the mainland, the European continent (96.6% of the country area), and the Azores and Madeira archipelagos. Portugal is Atlantic by geographic position but markedly Mediterranean by climatic and agricultural systems. Its climate is influenced by its location in the transition region between the Azores subtropical anticyclone and the subpolar depression region. In addition, its climate is strongly conditioned by its orography and the effect of the Atlantic Ocean. The diversification in climate factors is sufficient to justify significant precipitation (Fig. 22) and air temperature variations (Fig. 25). It could go from a total annual average of about 2500 mm in the northwest to 500 mm in the southwest region. Precipitation shows high interannual variability, with well-known vulnerabilities due to climate variability, namely droughts in the Southern sector and floods in the north.

Although the territory does not reach very high altitudes when compared to the highest in Europe, we can say that it is very rugged, influenced by the great diversity of microclimates, plant communities and productive potential, especially north of the Tagus River.

To have a good measure of the contrast between north and south, consider that north of the Tagus, 19.7% of the territory is located above 700 m concerning sea level, while in the south, this percentage reached 0.2 %. This contrast is defined by the development of the central mountain range from Spain, roughly in the NE-SW direction, with its most significant expression in Portugal in Serra da Estrela (1991 m) extending to Serra da Lousã.

As of December 31, 2020, the resident population in Portugal was estimated at 10,298,252 people, which resulted in an effective growth rate of 0.02%, resulting from a natural growth rate of -0.38% and a migratory growth rate of 0.40%. (Table 14).

Between 2015 and 2020, the proportion of young people (under 15 years of age) in the total resident population decreased from 14.1% to 13.4%; the proportion of people of working age (15 to 64 years) also decreased from 65.2% to 64.1%; in contrast, the proportion of older people (65 years and over) increased by 1.7 p.p. (from 20.7% to 22.4%). Consequently, the ageing index rose from 146.5 to 167.0 older people per 100 young people.

The North is the NUTS II region where the most significant number of people reside (3,566,374 in 2020), concentrating over the years of the period under analysis around 35% of the total resident population, followed by the Lisbon Metropolitan Area (2,869 033) and by the Centre (2,229,331), representing respectively around 28% and 22% of the total population (Table 14).

Table 14 – Total resident population by NUT II (Nºs)

	Portugal	North	Centre	M.A. Lisbon	Alentejo	Algarve	A.R. of Azores	A.R. of Madeira
2015	10,341,330	3,603,778	2,250,364	2,812,678	724,391	441,929	245,766	256,424
2016	10,309,573	3,564,575	2,243,934	2,821,349	718,087	441,469	245,283	254,876
2017	10,291,027	3,576,205	2,231,346	2,833,679	711,950	439,617	243,862	254,368
2018	10,276,617	3.572,583	2,216,569	2,846,332	705,473	438,864	242,846	253,945
2019	10,295,909	3,575,338	2,217,285	2,863,272	704,558	438,406	242,796	254,254
2020	10,298,252	3,556,374	2,229,331	2,889,033	609,420	437,970	242,201	253,923

Source: Estatísticas demográficas 2020 [Demographic Statistics]. INE, Portugal

Concerning the population aged 15 and over, the population increased (+0.4%) between 2019 and 2020. Considering the different age groups and as of 2019, the group from 15 to 24 years old continues to grow positively. There is a 1% increase in the number of women and a 0.3% increase in men in this age group. In the 25 to 44 age brackets, the population continues to decline, which has occurred almost since 2011. This decrease has been attenuating in the 25 to 34 age class, while it is accentuated in the 35 to 44 age class. The most significant increases were registered in 2020, as has been happening since 2011, in the age group of 65 and over.

Following a long negative trend since the 1980s, when the fall in fertility and birth rates was accentuated, the sharpest reduction in the population can be observed in 2020 (Fig. 34). This situation resulted from a migratory balance of 25,642 people, which did not compensate for the negative natural balance result, which worsened in 2021 to -45,220 (-38,828 in 2020).

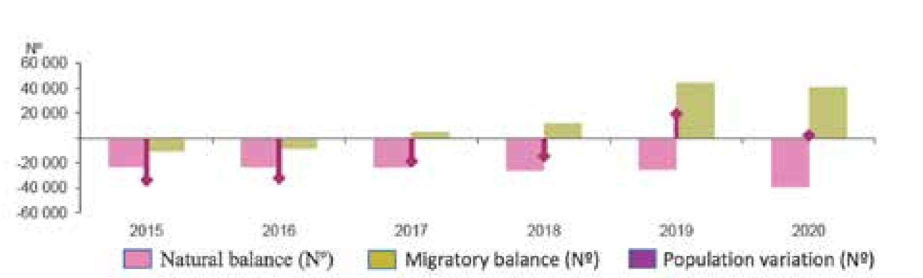


Fig. 34 - Population variation, natural balance and migratory balance, Portugal, 2015-2020

These results translated into effective, migratory, and natural growth rates of 0.19%, 0.25% and -0.44%, respectively. The data reveal a population growth lower than the demographic recovery rate and high ageing values (higher than 65 years), reaching 23%. If these trends continue, Portugal should arrive in 2040 or 2050 with a third of the population over 65 years old.

Just as climate and altitude, there is also a marked North-South contrast concerning human occupation. The South (Alentejo and Algarve) still have municipalities with less than 10 inhabitants/km² densities. In contrast, in the North municipalities, the density reaches a mean value of 171 inhabitants/km², and the municipalities surrounding Lisbon get a higher mean value of 932.9 inhabitants/km² (Table 15).

Table 15 – Synthesis of number of inhabitants and population density per district (reference values, 2021

Districts on the coast			Center and Inland Districts		
Name	Resident population	Population/km²	Name	Resident population	Population/km²
Lisbon	2,275,591	824.2	Coimbra	408,631	103.5
Porto	1,786,656	746.0	Viseu	351,592	70.2
Setúbal	875,656	172.9	Vila Real	185,876	42.9
Braga	846,515	312.8	Castelo Branco	177,912	26.7
Aveiro	700,964	250.5	Évora	152,436	20.5
Faro	467,495	94.6	Beja	144,410	14.1
Leiria	458,679	130.9	Guarda	143.019	25.9
Viana do Castelo	231,488	102.7	Bragança	122,833	18.7
			Portalegre	104,989	17.3

Source: Estatísticas Demográficas – 2020. [Demographic Statistics - 2000] INE, Portugal

Alcoutim, in the Southeast Algarve, occupies an extreme place in the demographic indicators in Portugal, but it is not alone. Oleiros, Idanha-a-Nova, Nisa, Vila Velha de Rodão, Mação, Gavião, Pampilhosa da Serra, Vinhais and Vimioso, among others, are now very old and with very low population densities. Many municipalities throughout the country's interior, from the North interior axis to the Algarve Mountains, have suffered from expressive emigration. Their populations are unable to regenerate themselves because they lack people at working and fertile age. It is an extensive strip where development has proved to be very difficult and where land abandonment and its consequent vulnerability to fires is felt more.

When comparing the human distribution of the coast with that of the interior, we can see that the population depletion of the interior becomes salient. This drainage from the interior to the coastal area, especially the younger ones, leads to a progressive solid increase in the abandonment of small family farming activities in the interior, with all the expected consequences in terms of increasing the vulnerability of these areas to fire and food sufficiency. It is also foreseeable that these depopulated areas will face increased difficulties in implementing the necessary adaptation and mitigation measures to deal with climate change and territorial cohesion.

The progressive abandonment of the small family farms and small private forest holdings is more perceptible if we look not only at the marked ageing of the population, which is more visible in the interior parts of the country, but also at the sharp decrease in the active population in the primary sector.

According to INE data, in 2020, the active population totaled 4908,8 thousand people on the continent and distributed by the three economic activity groups as depicted in Fig. 35 having decreased by 1.64 % compared to 2019. This drop was due to the number of active women (-1.51 %) and the number of active men, which decreased by 1.76 %.

Between 2011 and 2020, the weight of employment in the Services sector decreased by 0.7 p.p., having also fallen by 4.4 p.p. in agriculture, animal production, hunting, forestry and fishing and increased by 7.5 p.p. in Industry, construction, energy and water. Throughout the series, there was an increase of 327.3 thousand individuals employed in Services and, a decrease of around 85.1 thousand in Industry, construction, energy and water and 219.9 thousand in agriculture, animal production, hunting, forest and fishing.

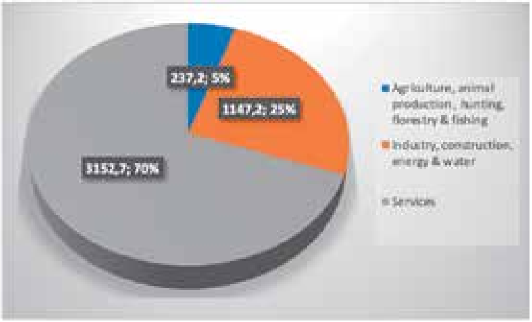


Fig. 35 – Breakdown of the Portuguese active population by sectors of economic activity (1,000 people) (2020). Data source: MTSS[435]

In 2020, the activity rate of the population aged 15 and over was 57.9%, a decrease of 1.2% compared to the previous year. The male activity rate was 62.9%, having decreased by 1.3% compared to 2019; the female rate, which was 53.6%, reduced by 1.1%.

Concerning age groups, the active population decreased by 11.5% in the youngest group (15 to 24 years), which applies to both men and women. The only increases occurred in the 45 to 54 age group (+1.6%) and the 55 to 64 age group (+1.2%). As seen with the resident population, the decrease in the number of active workers in the 25 to 34 age group has been attenuating since 2011 and progressively increasing in the 35 to 44 age group.

In 2020, the activity rate decreased in practically all age groups, except for those between 45 and 54 years old (+0.8 p.p.) and those between 55 and 64 years old, which did not change until 2019. As far as men are concerned, the activity rate only increased from 45 to 54 years old.

Between 2019 and 2020, the active population decreased in all regions: in the North (-0.1%), in Alentejo (-0.7%), in the Lisbon metropolitan area (-2.3%), in the Center (-3.2%) and the Algarve (-3.8%) were the regions where there was a significant decrease.

The Lisbon metropolitan area was one of the regions where there was a more significant decrease in the number of active men (-2.9%), compared to the number of active women (-1.7%), as well as the Algarve region, where active men decreased (-5.5%) while women were (-2.1%).

The region where the percentage of decreased active population between 2011 and 2020 was more pronounced was the Central region of Portugal.

If it is true that agricultural activity and its ability to produce depend on physical production factors that result from the combination of the biogenic characteristics of the soil and the climate,

[435] MTSS (2021) – Relatório sobre Emprego e Formação – 2020. Ministério do Trabalho, Solidariedade e Segurança Social. Lisboa, 285 pp.

we cannot forget the human factors that almost imperatively determined not only the structure of its production units as well as their ability to manage production factors.

The latest data show that the number of farmers in Portugal decreased by around 40% between 1999 and 2016. Despite this sharp drop, we are still above the EU average. This decrease in labour allowed for an increase in the agriculture productivity. Still, we are a country where the vulnerability of the activity is more accentuated because of its land structure and the structure of its active population. In demographic terms, 52% of Portuguese farmers are over 65 years old, the highest percentage in the entire EU; 4% are under 40. In addition to this constraint of insufficient generational renewal, we must mention that policies to reverse this trend did not materialize within the scope of the Rural Development Program[436] (PDR) (2014-2020).

Commenting on the low adequacy of the incentives designed within the scope of the PDR for population revitalisation, Livia Madureira[437] (2022), refers that "this incentive was designed in a context of the family succession of agricultural holdings in central and northern Europe, already with some size and capitalisation, and even then, it is not stopping the ageing of farmers".

The researcher, commenting on the criteria adopted for the incentives, refers to a critical problem that has been successively neglected in Portugal: "the creation and sharing of knowledge in agriculture". Innovation is increasingly being done with less workforce and more technology, and this creation and sharing have been lacking, even because the starting point was low. We should note that the Young Rural Entrepreneur Statute (JER) was only finally created in January 2019 after a long gestation process, but the definition of incentives is still pending. In this regard, Livia Madureira (2022) mentions the absence of an essential element for the effectiveness and efficiency of generational renewal instruments when she says, "*One of the great mistakes in the design of the establishment of people in the interior of the country is to ignore those who are already there and do not understand the importance of family and community dynamics. They need services, culture, and digitalisation, conditions necessary to encourage young families who are attracted to the "country lifestyle" but need to have perspectives for themselves and their children's education. In this aspect, it is known that the gap has not narrowed concerning the economy, development, social and school services*".

6.2 – Land occupation and a brief profile of the agrarian sector

In Portugal, most of the population is concentrated in the coastal zone; the Gross domestic product (GDP) is around €207,051.6 million (2020), representing a per capita of 17 910 euros. The average annual expenditure of families reached 20,363 euros (about 2.5 people per household), where expenditure on food and non-alcoholic beverages represented 14.3% (INE, 2017a).

From the ecological conditions briefly described, the topography and geological constitution of the territory result that the soils, usually sloping, especially north of the Tagus River, are thin, easily erodible, and not always easy to technology innovations. On the other hand, due to the irregularities of the climate and the torrential rain regime, we can see that many valley soils with low slopes, great thickness, and high fertility levels often need irrigation in the summer and drainage in the winter, which makes them sometimes difficult to use in agriculture.

---

[436] Programa de Desenvolvimento Rural 2014-2020. Documento de Orientação, GPP, Ministério da Agricultura, do mar, do Ambiente e do Ordenamento do Território, 2012, 67 pp.

[437] Madureira, Livia (2022) – [citation in: Soares, Tiago, Terra Velha, Expresso Revista, 6th Agosto, 9-10

According to the SROA, only 35% of Portugal's soil should be used successfully in agriculture, although always with some restrictions. For example, this figure for Belgium is 52% and 78% for England. It follows (Gaspar[438] et al., 1987) that there is only 0.10 ha of agricultural land per inhabitant, while the European average is 0.22 ha. The CNROA (Mendes,[439] 1987), summarises the recommended future use in Table 16.

Table 16 – Land Use Capability in Portugal

Land occupation	Current (%)	Future (%)
Agriculture	54	28
Forest	19	31
Agroforest	12	35
Unproductive	13	--
Others	2	6

Source: Mendes (1987)

Portuguese inland ground cover depicted in Table 17 characterize the state of the forest in 2015, which is already different from its current situation, as a result of the natural dynamics of the ecosystems and their interface with the agricultural sector, namely those resulting from the transfers of use between the two sub-sectors according to economic and social dynamics that favour more profitable use options, without forgetting, also, the consequences of the rural fires of 2017, 2019 and 2021.

A more detailed spatial analysis of the relative variations of Land Use-Land Change (LULC) shows that the relative variation of LULC over the four decades under analysis is quite variable depending on the type of LULC and the region under analysis. In the case of the Agricultural class, the data point to a reduction in all regions. Here the Algarve region showed the greatest loss and the Alentejo region the smallest; already in agroforestry, there were losses in the North, Centre and Alentejo regions, while the increases occurred in the Lisbon (higher value) and Algarve regions.

In this assessment, Forest Inventory (2015), the artificialized (urban) class occupation stands out with an increase in all regions. The two regions in the South of Mainland Portugal stand out with the most significant relative increases in this type of occupation. Water bodies increased mainly in the Alentejo Region, although the Central Region also rose less than in Alentejo. In Forest cover, the soil with this type of LULC decreased in several regions, except for Lisbon, where a slight increase was observed.

Despite the tendency of reduction of the forest area, as observed since 1995, the last inventory shows a reversal of this trend as verified in this last inventory, which registered an increase of 60 thousand ha (1.9%), future expectations for Portuguese forests are not rosy. The reduction in forest area, more expressive for maritime pine, is a relevant aspect of the forest occupation area, economically and environmentally. This negative trend was already shown in 1981 by the

[438] Gaspar, A. Mendes et al, (1987) – Utilização dos solos portugueses para culturas não alimentares (excluindo as produtoras de madeira), Relatório solicitado pela JNICT no âmbito do Programa FAST II das Comunidades Europeias, Lisboa.

[439] Mendes, F. Louro (1987) – A floresta e as pastagens. In: Ordem dos Engenheiros, 10

FAO/WB technical assistance mission that predicted, even assuming that forest fires could come to be controlled and that private producers could be persuaded to introduce more appropriate management practices, a strong probability of occurrence of a critical retraction in the supply of pine wood even before the year 2011 (Fig. 36).

Table 17 – Portuguese inland ground cover (1,000 ha)

	Land use areas (1,000 ha)					
	1995	2005	2010	2015		Δ(2005-15) (1,000 ha)
				Area	%TU	
Forest	**3305,6**	**3215,9**	**3164,2**	**3224,2**	**36.2**	**+8.3**
Wooded area	2792,8	2901,7	2948,8	2987,1	93.6	+85.4
Temporarily deforested area	512,8	314,1	215,3	237,0	7.4	-77.1
Cut off	15,6	28,3	38,0	98,7	3.1	+70.4
Burned	44,3	104,6	30,0	12,6	0.4	-92.0
In regeneration	453,0	181,2	147,4	125,7	3.9	-55.5
Agriculture	**2407,3**	**2204,7**	**2117,2**	**2092,9**	**23.5**	**-111.8**
Bushes & Pastures	2539,6	2716,7	2832,1	2762,2	31.0	+49.5
Unproductive land	190,3	195,8	185,4	191,7	2.2	-4.1
Inland waters	151,9	178,2	184,2	192,8	2.2	+14.7
Urban	315,5	399,0	427,2	442,4	5.0	+43.4
Total areas by forest species (1,000 ha)						
Maritime Pine	978,0	798,0	719,3	713,3	22.1	-84.8
Eucalyptus	717,2	785,9	810,8	845,0	26.2	+59.1
Cork oak	746,8	731,2	717,4	719,9	22.3	-11.3
Holm oak	366,7	335,5	349,2	349,4	10.8	+13.9
Other oaks	92,0	66,3	67,2	81,7	2.5	+15.4
Stone pine	120,2	172,9	184,6	193,6	6.0	+20.7
Chestnut	32,7	38,4	42,7	48,3	1.5	+10.0
Carob tree	12,3	12,2	12,0	16,4	<1	+4.2
Acacias	2,7	4,7	5,5	8,4	<1	+3.7
Other broad-leaved trees	155,2	169,5	176,0	190,2	5.9	+20.7
Other resinous	61,4	73,5	71,1	52,2	1.6	-21.3
Temporarily deforested surface	20,6	27,6	8,1	5,7	<1	-22.0

Source: 6º Inventário Florestal National. Relatório Final [6th National Forest Inventory, Final Report], ICNF, 2015

This downtrend in pine forest supply demands careful attention from public authorities and society, mainly after the enormous disturbances to which the pine forest was subjected due to the severe forest fires of the last two decades (more than 2.8 million hectares affected by fire) and pests that have severely affected the national maritime pine forest, or the retraction of the cork oak formations.

From 2001 to 2022, Portugal lost 1.17 Mha of tree cover, equivalent to a 51% reduction since 2000 (Global Forest Watch[440], 2023). In regional terms, five main regions were responsible for the loss of 51% of all tree cover between 2001 and 2022, distributed as follows:

- Coimbra -146 Kha;
- Castelo Branco - 130 Kha;
- Viseu - 123 Kha;
- Aveiro – 92 Kha
- Santarém - 103 Kha;

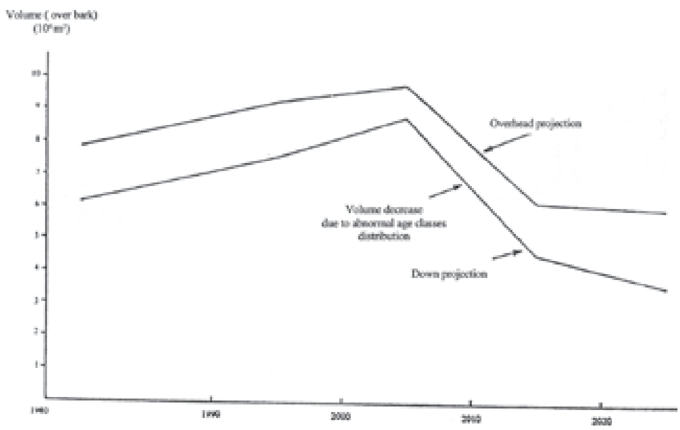


Fig. 36 – Future trend supply projection of maritime pine wood
Data Source: Projecto Florestal Português – Programa de Assistência Técnica UTF/POR/001.1981[Portuguese Forestry Project – Technical Assistance Program]

From 2000 to 2020, and according to data from that organization, Portugal recorded a net change of -104 kha (-3.4%) in tree cover. The components of the net change in forest cover in Portugal were: Stable Forest – 1.69 kha; Loss-273 kha; Disturbed-1.15Mha.

Clear spatial planning policies are necessary to modernize and transform the use of land in Portugal, mainly to avoid the disordered growth of urban areas and to support the options regarding territorial cohesion interventions and the recovery of burned and abandoned rural areas. In addition, it is to mention the existing insufficiency of effective control instruments, such as regional land use plans for the landscape units, without which interventions are mainly casuistic or derive from processes with a dubious or hazy legal origin that contribute to disturbances of large areas, especially in metropolitan areas and for the degradation of essential landscape places across the country, generating negative ecological externalities. Without these

[440] Global Forest Watch [https://www.globalforestwatch.org/dashboards/country/PRT/]

reference frameworks, the objectives of the technicians are naturally biased by the most dominant economic references. Corroborating this statement, a relatively recent study (Kolos[441], 2020) on the common areas (baldios) occupying around 500,000 ha states that "*most managers of common forest areas are mainly concerned with the profit from these areas and not with environmental issues. Currently, little or no attention is paid to the importance of ecosystem services in these common forest areas, even under co-management arrangements*".

If current trends continue, the threats pending upon Portuguese forests are expected to compromise the goods and services provided by the forest ecosystems. Secondary processes such as converting forests to scrubland, forest fires, pest, and pathogen outbreaks, overgrazing and land abandonment, whether for economic reasons or depopulation, are strong drivers of forest degradation and loss of environmental benefits. Failure to act to actively address these threats and degradation factors will ultimately lead to the loss of natural capital provided by forests and trees outside forests in Portugal.

In the continental territory, one can observe an agriculture and forestry production specialization in some regions, namely "Alto Alentejo", "Lezíria do Tejo", "Baixo Alentejo", and "Entre Douro e Vouga", where the agroforestry complex represents, respectively, 18 %, 16% and 14 % of the respective regional product. It should be noted that while primary activities predominate in the Alentejo sub-regions, in "Entre Douro e Vouga", the main goal is the generation and industrial conversion of agroforestry products.

6.2.1 – The forest sector

6.2.1.1 – The forest service overview

Historically, the relationship between rural communities and the forest has been long in Portugal, as well as in the Mediterranean, Western Europe, and almost all countries in the southern hemisphere. It can be said that the woods provided the necessary resources for many vital transformations in economic and social history and environmental aspects of societies. In the past, rural people depended heavily on forests for shelter and to provide a wide variety of products necessary for their livelihoods, from food, medicinal plants, energy and building materials and certainly as a land reserve for expanding the agricultural area when required. Although forests were an essential component of traditional agricultural systems, the lack of knowledge about this virtuous relationship has led to the large-scale degradation of agrosystems in Portugal. Suffice it to say that around 1868, forest cover in Portugal reached a derisory value of around 7% of the territory and erosion and flooding reached severe proportions in the Vouga and Mondego valleys.

Over the centuries, the diversity and complexity of social and economic development have driven changes in production systems and resource appropriation that have profoundly altered the intensity and nature of the relationship between rural communities and the forest and have almost always been a source of rural social problems. The Portuguese Forestry Services, responsible for the thorny task of recovering the Portuguese forest and safeguarding natural spaces, were thus at the centre of the controversies that involved the occupation of vacant and degraded land and the planning of community lands (*Baldios*). Although the issues of land valuation policies and land tenure systems (commonly referred to as the Baldios issue) are

[441] Kolos, Irina S. (2020) - *Governance of Community Forest Areas in Mainland Portugal Over the Last 40 Years: Results, Current Trends and Future Perspectives*. D. Ph. Thesis, Lisbon University, 399 pp.

outside the scope of our analysis, their relationship, which we would say turbulent, with the institutional development of the Portuguese Forestry Services and afforestation/reforestation of the territory justifies its reference here. Refer to Annex I for a more detailed analysis of its evolution and the controversies surrounding this issue.

Furthermore, it should not be forgotten that the commons have long been a central idea in environmental studies, and the resources and institutions described by this term have long been recognized as central to many environmental problems (Dietz[442] et al., 2002).

Since the creation of the Forest Service in 1824 (this designation is used generically because, throughout its existence, its name has changed frequently), three fundamental concerns stand out to the authorities: firstly, the afforestation of coastal dunes (public property) with a view to the security and protection of adjacent lands against sea winds; secondly, the need to know the physical dimension of the Portuguese forest; thirdly, the institutional design to be erected to respond to the needs of afforestation and territorial forest management. In this context, from 1868 to 1878, studies were carried out to identify, as accurately as possible, the state of occupation of the territory and the reality of Portuguese forests.

Although in 1878, the identification and knowledge of the essences that made it up were already complete, thanks to Bernardino Gomes, there were controversies regarding the different areas of land use, namely the land that should be allocated to the forest. The following period of the Portuguese forest renaissance, as mentioned by Radich[443] and Monteiro Alves (2000), was the 1910 Agricultural and Forestry Charter which was fundamental for determining the areas corresponding to the cultural division of the territory that reached "*a threshold of precision that the 20th century itself had difficulties to overcome*".

The afforestation of the uncultivated land gained a significant dynamic (1938-1968) with the Forest Development Law focused on the Commons north of the Tagus River. It was a controversial period where the afforestation carried out by the State ended up in polemics. Such is the case of disputes between agrarians and foresters over the leadership of the Commons, the latter gaining some ground with the growing triumph of industrialists from the mid-1930s onwards. Foresters claimed that the lands where the State intervened had previously been covered with forest. This original forest cover had disappeared because of the unwise exploitation of this land. In this way, foresters presented their enterprise as an act of territorial healing or restoration. Further, the introduction of state forestry was defended regarding the nation's well-being benefiting the common good. Likewise, the choice of forest species to be used in the afforestation tasks ended up also generating divergences, where the ideals of nature protection and a more economic vision of the forest clashed.

During this long period, a source of friction with the populations was the deficient discussion and sociological weighting, and mainly of lack of strategies for the participation of the people to minimize the resistance of the mountain populations regarding the impact of the actions resulting from the sudden changes imposed in the modes of traditional life.

The second half of the 20th century has represented a turning point in the country's forest policy and the composition of the forest area, with the growing importance of Eucalyptus

---

442 Dietz, N.D, Ostrom, E., and Stern, P.C. (2002) – *The Drama of the Commons*. Committee on the Human Dimensions of Global Change. Eds. Division of Behavioral and Social Sciences and Education. Washington, DC. National Academy Press, 534 pp.

443 Radich Maria Carlos e A. A. Monteiro Alves, A.A. (2000) - Dois Séculos da Floresta em Portugal, Lisboa, CELPA, Lisboa 226 pp.

globulus and the focus on the afforestation of private lands. This turn, regarding forestry policy objectives, corresponds to a substantial geographic change in the region targeted by the expansion of afforestation, dominated by the "southern fields of Alentejo". In this new framework, Radich and Monteiro Alves (2000) highlight Law No. 2069 of 1954 (that instituted the Forest Regime) as the first legislative measure to respond to the exhaustion of Alentejo soils. But it marks a strengthening of the connection between the forest and industrialization, namely with cellulose, particle board and panel wood. Remember Westoby[444] (1962) in his classic paper "Forest Industries in the Attack on Economic Underdevelopment", reinforced the conceptual framework of forest-based development with a robust inter-industry linkage and growth effects.

In addition to recovering soils degraded by wheat campaigns protecting mountain soils and water resources, the Forest Regime had the ambition to support private forest producers and encourage wood tree planting. Unfortunately, its application to private property, due to plantation costs and associated conditions and obligations, became an instrument of support for large landowners. Note that in 1960 the average area of private properties subject to the Forestry Regime was 695 ha per property or group of properties (Baptista[445], 1993).

Support for the afforestation of private property also took a new impulse with the creation and dynamization of the 1965 Forest Development Fund (FDF) (Azevedo Gomes[446], 1967). The importance of the fund can be appreciated due to the impulse it provided for the reinforcement of a renewable forest resource and its significance in strengthening the supply of raw wood material for the industrialization of the sector. This context is enhanced under an environment wherein: i) tiny forest property predominates; ii) there is a long-term problem with obtaining productive economic results; and iii) the average low profitability of the exploitation, combined with high costs of reforestation and with very high interest rates.

Thus, it is unsurprising that it was the Alentejo, where the dimensions of farms were more extensive and signs of soil degradation were more accentuated due to the wheat campaigns, that benefited most from the FDF interventions. Indeed, in addition to that instrument that specified that the minimum area of intervention would apply to areas greater than 50 ha, Azevedo Gomes is clear in assuming, regardless of the possible controversy, that the objective of the afforestation instrument created was "*to recover the soils of private properties classified as having the capacity to be used mainly by forestry, and in accelerated pace, sustaining productions that are in harmony with their respective potentialities, even admitting that such an enterprise may come in certain regions to support or aggravate a social stratification to a certain extent contrary to the purpose of economic development*". To his mind, it would be up to political power to guide the development and necessary adjustments for social development and improve social justice.

To support that point of view, we think it is helpful to remember that in the field of forestry production, apart from its peculiar characteristics, silviculture should behave, under penalty of not fulfilling its mission of creating goods and services, like any other economic activity, subject to various influences, from the game of supply and demand to interest rates linked to the security of invested capital, and which have to be coordinated and integrated into the national economy as a whole, and behave like any other capital investment, working at acceptable interest rates.

---

[444] Westoby, J.C. (1962) - The role of forest industries in the attack on economic underdevelopment. Unasylva 16: 168-201

[445] Baptista, F. O. (1993) – A Política Agrária do Estado Novo. Ed. Afrontamento. 420 pp.

[446] Azevedo Gomes, A.M. (1967) – Fomento da Arborização nos Terrenos Particulares (Planeamento para o Sul do Tejo). Fundação Caloust Gulbenkian, Lisboa. 398 pp.

Under our current economic model and in the current agro-silvo-pastoral adjustment, the production forest can hardly fail to be understood as a field of application of capital, not isolated from a world of activities characterised by the rarity of this same capital, which, for that very reason, receives, in the form of interest, the respective payment. In this context, prioritising the southern region and a policy of large afforestation areas was perfectly understandable. Given the smallness and dispersion of private woods, promoting economies of scale in producing raw wood and cork was the most capable of maximising the sustainable profitability of the investments made in afforestation.

In 1970, the FDF enlarged its area of intervention studying the first smallholdings intended for afforestation and began the execution of work on associative afforestation centres, which had their heyday between 1973-76, in the districts of Castelo Branco, Guarda Coimbra, Leiria and Faro.

In terms of forestry policy, the last twenty-five years of the 20th century were marked by the afforestation strengthening of the private property, but this time with the financial support under the aegis of the FAO/World Bank[447] (1982-1988).

The need for an afforestation program stemmed from the fact that, in the evaluation phase of these investments, projections were made of the balance between supply and demand for woody raw material that pointed to a foreseeable short-term shortage of both eucalyptus and pine.

Despite not having achieved all of its goals, the Portuguese Forestry Project (known as the World Bank Project) was undoubtedly the last significant forestry promotion intervention in which the Portuguese Government requested funding from the FAO/WB for a project to increase the capacity of the wood pulp production at two PORTUCEL units and the construction of a new facility, which would become SOPORCEL.

The levels of material achievement (considering the extension of the deadline for closing the project to 1988) of the proposed actions were as follows:

	Projected	**Achieved**	
• Total afforestation	- 150,000 ha	- 132,000 ha	
			21,572 in private owned land
• By the State	- 90,000 ha	- 71,908 ha	{ 50,336 in common land}
• By the PORTUCEL	- 60,000 ha	- 45,500 ha	
• Associative promotion in private own forests		- Meaningless results	
• Financial execution rate	– 100 %	- 87 %	

Notwithstanding its importance, the WB project had limited effect in mobilising the small forest landowners for a collective adoption of measures needed to allow better conditions for enhancing production capacity and forest management of small holding plots; neither had its significance in improving the creation of a forest extension service to mobilise small forest owners or enhancing the underdeveloped research. Joint adoption is not a mere aggregate of many acts of innovation adopted by atomistic individuals but a process of interlinkage among individuals

[447] FAO/World Bank (1982) – Desenvolvimento Florestal, Portugal. Estratégia para o Desenvolvimento do Sub-Sector Florestal, FO: DP/UTF/POR/001/POR. Relatório Final. 209 pp.

and their purposeful action for achieving a new common objective, which the Forest Service could not realise.

Processes such as reforestation/afforestation, environmental protection, watershed rehabilitation, and general group protection and management of natural resources depend largely on collective action and collective innovation, which the project could not trigger. The necessary reorganisation and reinforcement of means of the Forestry Services were already felt here. Government instability, lack of appreciation of the importance of forestry, absence of unclear forest policy and evident lack of participatory strategy meant that the State only accomplished 71,908 ha of its target. Most of the proposed infrastructure, extension service, research reinforcement, and credit programme were not implemented.

Unfortunately, Forest Service planners and policymakers have not realized that considering social factors in interventions, such as afforestation involving local populations, must be woven into the very fabric of such programs from the outset. The penalty for ignoring social factors is project failure or partial realization.

The new public interventions in the forestry sector after that date did not remove but worsened the constraints that were pointed out at the onset by the FAO/WB project: i) The need to encourage broad participation of small forest owners in a properly planned program of improvement of their forests; ii) The negotiation of land for afforestation in areas large enough to justify the investment and in a timely manner to allow the planning of plantations; iii) Coordination between the multiple ministries and bodies involved with the forestry sector in order to give cohesion to forestry policy; iv) The establishment of legislation with the objective of facilitating the aggregation of properties into minimum area of viable management, forcing minimum standards of forest management; v) Institutional strengthening of the Forest Services to ensure their cohesive intervention which should be reinforced with the creation of a technical extension service with sufficient staff to operate efficiently at the field level, to motivate the development of private forest areas and assist in the promotion of Forestry Cooperatives; vi) The strengthening of forestry research, which must be intensified and oriented to meet the specific needs of the development strategy. All forestry research must be coordinated to give it cohesion with the approved development priorities and, last but not least, the urgency to control forest wildfires.

However, the process for this type of intervention in the small forest property lost rhythm and ended in 1984, as also happened to the FDF.

A brief review of the output of the FDF shows that, despite the frequent changes in its institutional and financing framework, it allowed 253,000 ha to be afforested, having created, or intervened in over 70,000 ha of pastures (Louro, 2016).

In the context of adhesion to the EU, the Forest Action Program, with a duration of ten years, and the timid Forest Development Programme (1994 to 1999) mark the end of the continued growth phase of the Portuguese forest. Despite that significant funds had been available to support forestry through several financial instruments (PEDAP, Reg-CEE 3828/85, FEDER and FEOGA) totalling 111.52 million ECU, Portuguese forests are again in a downturn trend, and the pine area from 1995 to 2015 decreased more than 265 thousand ha. Ill-conceived strategies, policies, and permanent wildfires are curtailing the forestry sector's capacity to supply the current industrial demand and employment in rural areas and have minimal effect in removing the main bottlenecks affecting the forest sector.

Regardless of the winding path covered by the Forestry Services and the changes and misunderstandings to which they were almost always subject, it is worth mentioning the significant rate of afforestation achieved with such a low starting point. However, it did not resolve the obtrusive structural problems arising from the fragmentation of forest ownership or the clarification of land tenure over a large area. Its extinction, replaced by a new organization, the ICNF, did not introduce a better approach to the treatment and management of Portuguese forests, nor to the organization or dynamization of private forestry, nor did it contribute to a better vision of the role of the woods in the context of economy and development of the forestry industry or its essential part in the environmental context, neither made forest spaces safer about fire risks nor made them a more important instrument in terms of their contribution to carbon sequestration. The emptying out of the Forestry Services and many of its specialized intervention and control services to deal with forestry problems, some of which were not included in the ICNF, needs to be addressed to create a stable investment environment.

In Portugal, the sector is subject to the instruments of political administration provided for in the 1976 constitution and to that established by the 1996 "Forest Policy Basic Law" and subsequent specific legislation. Different government programs and the National Forestry Strategy have defined the sector's global evolution, approved in 2006 and updated in 2015. This strategy is translated territorially by 22 Regional Forest Management Plans (PROF) (21 for the mainland and 1 for the Autonomous Region of Madeira. Although the current regulation defines that public and community forests above a specific size and Forest Intervention Zones (ZIP) must have a Forest Management Plan, the ICNF (2021) mentions that on the mainland, forest management plans only cover 35% of the forest area, which we must admit is more than a modest indicator of the efficiency and effectiveness of the management of this critical natural resource in Portugal. Stone pine, cork oak and eucalyptus woods have a forest management plan coverage rate higher than the national acreage.

In this regard, several tools have been developed in recent decades to promote sustainable forestry, of which Forest Certification is one of the most important. Oriented both to public and private actors and in the perspective of preserving ecosystem services provided by forests, also considering climate change, certification aims to improve forest practices in environmentally sustainable and socio-economically viable ways, complying with principles and criteria for correct forest management.

Numerous forest certification schemes exist, but the Programme for the Endorsement of Forest Certification Schemes (PEFC) and the Forest Stewardship Council (FSC) are the most recognized and diffused. These two approaches are profoundly different, especially regarding forested surfaces. In this regard, values found for Portuguese Forestry (Maesano[448] et al., 2018) show that the area under FSC and PEFC monitor schemes was 337 Kha and 236 Kha, respectively.

The national number falls far short of the European reality, whose average was 70%.

Over time, until today, governments have been manifesting intentions, programmes, legislation, and inscribing funds in their respective budgets, almost always in the same amount year after year (forgetting the devaluation, the increase in the costs of intervention factors and the need to reinforce forest restoration), which seems to us to be revealing that, in fact, the Government has no strategy. Intentions have remained unrealised, and achievements are consistently below what would be possible with another operating structure. Intentions have remained unrealised, and achievements are consistently below what would be possible with another operating structure. In the words of Louro (2016), "[*the variety of legislative and institutional solutions, the ups and downs*

[448] Maesano, M., Ottaviano, M., Lidestav, G., Lasserre, B., Matteucci, G., Scarascia Mugnozza, G. and Marchetti, M. (2018) - Forest certification map of Europe. *iForest-Biogeosciences and Forestry*, 11(4): 526 - 533.

of political will, demonstrate that the objective of expanding afforestation on private property has always been a bit of a meandering line and wanting to straighten out without achieving it] ".

In the political approaches that have been made to the forest sector and the continuous complaints about its inefficiency and insufficiency to change the pace of afforestation and reforestation of the extensive burnt areas and in the improvement of forest management and fire prevention work, it seems that the critical role of the institutions and their adequate design to be able to achieve policy objectives is always left aside. It looks as if responsible authorities forget that essential organisations of forest management may have different interests, and their institutional analysis is crucial to the success of forestry (Schlüter[449], 2007).

It is generally acknowledged that institutional design and structure facilitate easy organisational interactions and reduce the current functioning cost. It is the key to maintaining good economic performance and a flexible institutional endeavour capable of being adjusted in the context of technological and demographic changes (North[450], 1990). In a changing economy, such as the one we are undergoing, institutional change is a complex multilevel process triggered by a combination of external changes and internal knowledge accumulation. Unfortunately, this aspect is heavily neglected for the Portuguese forest despite its socioeconomic and environmental importance.

Despite the funds made available by UE, the current situation of the sector, which is reflected in the recent reduction in area and the supply of woody material, as well as the current state of the forests, except those belonging to large industrial organisations, speak for themselves.

The multitude of entropy-generating actors in the decision-making and execution system (see the matrix in Fig. 37) and the absence of a genuine technical extension service do not provide a favourable climate for private investment nor for the performance of a service that everybody recognises its importance to help to mitigate climate change pace and for the economy of the country.

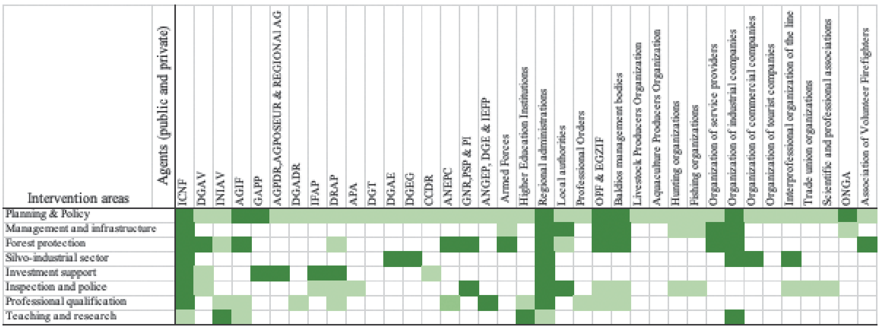


Fig. 37 - Matrix of institutions and areas of action in the implementation of forestry policy in Portugal Source ICNF (2021)

It is recognized that all large natural and artificial systems face complex coordination problems, and excessive partition of the decision-making process does not provide an efficient

[449] Schlüter. A. (2007) - Institutional change in the forestry sector—The explanatory potential of New Institutional Economics. *For. Policy Econ.* 9: 1090–1099. [https://doi.org/10.1016/j.forpol.2006.11.001]

[450] North, (1990) - *Institutions, Institutional Change, and Economic Performance: The Political Economy of Institutions and Decisions*, Cambridge. ed. Cambridge, Cambridge

and robust use of information. Here, the organizational problem is not to divide but to group joint activities with strong interactions strongly linked to the National Responsible Forestry Organization (NFRO). By doing so, the NFRO can assign specific decision-making responsibilities to those responsible at lower levels and allow it to better monitor accountability and reward based on contribution to national targets. Avoiding disharmonious incentives, as can arise when the responsibility shared by the different levels and intervening entities is not clear, is a big problem for the management of complex ecosystems because it can seriously attenuate the national, regional, and local coordination and the achievement of the National Forestry Targets.

With the current organization, it is, therefore, not a surprise when we see in a country with the scourge of forest fires and where prevention measures are essential, that the execution of the PDR 2020 fell far short of expectations: 60% of applications for fire prevention interventions did not have budget allocation and that its execution rate stood at 45%. In seven years, the area of approved projects stood at 2.4% of the continent's forest (Cardoso[451], 2023). In a country with around 400,000 forest owners, the measure only attracted 2,213 applications, revealing the ineffectiveness of the country's political and operational forestry structure and the consequent poor design of the available financial instrument.

Who doesn't know the frequent complaints from our entrepreneurs regarding delays in obtaining licenses and decisions on projects in the various public administration bodies, especially those that depend on the Ministry of Agriculture or the Environment?

6.2.1.2 – Territorial cover and typology

In 1965, when the first National Forest Inventory was published, Portugal began to present a systematic periodic forestry assessment process. In 1965-1995, the forest area increased significantly, with a covered area totalling 3,305 thousand ha. However, since these data, until 2010, the total size of the forest regressed to a value of 3,164.2 thousand ha, having increased between 2010 and 2015 to an area of 3,224 thousand ha.

From the analysis of Table 17, reflecting the land use scenario in Portugal, we extract the general picture (2015) of the forest area in Portugal:

a. Forest spaces (forest, bush, and unproductive land) occupy the national mainland's 6.2 million hectares (69.4%).
b. The forest includes wooded land (private, communal, and public), burned land and regeneration accounts for 3,224 million ha (36.4%).
c. The trend of decreasing forest area, observed since 1995, was reversed in 2015, registering an added value of 60 thousand ha (1.9%) compared to 2010 (data from the last assessment).
d. The national forest is mainly composed of native forest species (72%), although they occupy territories larger than their geographical origin.
e. In structural, functional, or environmental terms, the continent forest is organized into four groups: large forest formations - pine formations (consisting of maritime pine and stone-pine); evergreen hardwoods ("montados", cork oaks and holm oaks); deciduous hardwoods (oaks, chestnuts, and others); and silvo-industrial hardwoods (eucalyptus).

[451] Cardoso, Margarida (2023) – Floresta. Execução do PDR nas medidas de prevenção de incêndios fica nos 45%. Expresso, Economia, Maio 19.

f. The "montados" (cork oaks and holm oaks) are the main forest occupation, with about 1 million hectares representing 1/3 of the Portuguese forest. They are multiple use forests whose primary functions are not timber production but NTFP.
g. Deciduous hardwoods (oaks, chestnuts, and others) are the least representative forest formation in the occupied area. They showed, perhaps thanks to the increase in public perception of the ecological importance of native species, a significant growth between 2005 and 2015 of 46,000 ha (17%).
h. Bushes and pastures represent the second most expressive category of land use (31%). The bushes have increased continuously since 1995, naturally constituting a substrate for the dangerous propagation of rural fires.

Overall, the evolution of rural land use in the period in question (Table 17) reveals a continuous negative trend in forest cover until 2010, an increase of 8.3 thousand ha for 2010-2015, and a constant reduction in agricultural area. It should be noted that agriculture is almost always cited as one of the leading causes of the decrease in forest area. This is not the case in Portugal, as the agricultural area also suffered a reduction of 111,800 ha resulting from the abandonment and increase in bush and extensive pasture. It is also worth mentioning that in the 1990s, there was an average annual burned area of around 50,000 ha (AGRO GES[452] , 1996), and the afforestation rate was around 24,000 ha/year in the same period. The current situation is much more severe today. In fact, on the mainland and the island of Madeira, recurrent fires, and pests (especially in pine, eucalyptus, and oak trees) are responsible for the most significant loss of treed area and productivity, with 63,000 ha of average area burned annually in the last decade.

Considering the intensity of the fires, particularly in 2017 and 2022, it is expected that with the modest afforestation efforts and the low registered regeneration already shown in the last survey, they will have cancelled the increase in forest area verified after that date.

The last inventory shows that the area covered by maritime pine reached 713,3 thousand ha, a sharp decrease of 84.8 thousand ha in the short period 2010-2015. This significant decrease resulted not only from the considerable abandonment of the country's interior but also because it was the species most punished by the intense fires that affected the Portuguese forest.

Regarding wood production generated by national forests, the last forest inventory (2015) reveals that the volume of growing wood (i.e. live trees) of maritime pine decreased by 15 Mm3 compared to 2005, amounting to 67 Mm3 in 2015. The volume of eucalyptus wood growing to 143 Mm3 remained constant during 2005-2015, despite the increase in the area of 59 thousand ha. These values mean that the availability of maritime pine wood is decreasing and that the rise in eucalyptus wood does not follow the increase in area. Currently, there is already a structural deficit of pine wood estimated (2018), representing 57% of national industrial consumption. Existing information suggests that this deficit will worsen due to the marked loss of maritime pine areas by fires and abandonment, whose areas are not compensated by the pace of afforestation/reforestation. Not only are the new pine forests young, but the proportion of irregular and under-populated stands has been increasing, falling below their productive potential, as seen in Tables 18 and 19.

---

[452] AGRO GES, BPI and JA AKKO PÖYRO (1996) – Proposta para o Desenvolvimento Sustentável da Floresta Portuguesa. Sumário, 11 pp + anexos.

Until the end of the 70s, the oscillations observed in the maritime pine forest were relatively small. However, after a slight increase in this area, thanks to the WB project, a downward trend began, initially not very pronounced, but then took on a much more intense pace.

In the dominant pure and mixed stands, the losses are concentrated preferentially in the coastal districts, with a more excellent productive aptitude for the species (Viana do Castelo, Braga, Porto, Aveiro, Coimbra, Leiria and Santarém). As maritime pine wood is the most significant raw material for the country's sawn wood and furniture industry, and there is no concerted and far-reaching action to ensure the reforestation of the pine forest, the respective sector is already suffering a clear retraction in the supply of wood for its industry, thus reducing its capacity for local employment and also reducing its economic contribution to the regional economy. The current need to import wood to satisfy the installed capacity significantly harms the sector's trade balance.

Table 18 - Areas by species according to composition

Species	Composition	Areas (1,000 ha)				Δ (2005 – 2015)
		1995	2005	2010	2015	
Maritime pine	Pure	641.3	563.8	530.9	507.3	-56.5
	M. dominant	78.7	91.0	95.5	107.2	+16.3
	M. dominated	50.2	61.8	70.2	85.8	+24.0
Eucalyptus	Pure	592.1	642.6	674.5	688.7	+46.1
	M. dominant	55.9	65.3	73.3	78.1	+12.8
	M. dominated	26.8	37.7	42.2	52.5	+14.8
Cork oak	Pure	648,5	668.8	653.2	658.1	-10.6
	M. dominant	36.9	41.8	42.7	47.0	+5.2
	M. dominated	27.4	30.5	31.9	38.5	+8.0
Holm oak	Pure	327.2	318.9	332.5	332.5	+9.6
	M. dominant	9.9	10.1	10.8	13.3	+3.2
	M. dominated	11.4	14.7	15.4	15.7	+1.0
Oaks	Pure	38.0	40.8	42.9	50.1	+9.4
	M. dominant	19.4	21.5	22.2	26.6	+5.1
	M. dominated	11.2	13.3	13.1	14.0	+0.7
Stone pine	Pure	92.1	136.6	152.0	160.0	23.4
	M. dominant	19.7	24.5	26.0	29.2	+4.7
	M. dominated	22.8	25.7	25.1	26.4	+0.8
Chestnut	Pure	25.6	34.7	39.2	43.4	+8.8
	M. dominant	1.9	2.5	2.9	3.3	+0.8
	M. dominated	2.3	3.1	3.4	2.9	-0.2
Carob tree	Pure	12.1	11.9	11.7	14.7	+2.8
	M. dominant	0.2	0.3	0.2	1.6	+1.3
	M. dominated	-	-	-	-	-
Acacias	Pure	1.7	2.9	3.5	4.8	+1.9
	M. dominant	1.0	1.7	1.8	3.1	+1.4
	M. dominated	3.2	4.4	5.2	8.2	+3.7
Other hardwoods	Pure	118.2	126.3	132.9	136.0	+9.7
	M. dominant	22.4	29.9	34.9	42.7	12.8
	M. dominated	77.7	83.5	90.7	97.0	+13.5
Other softwoods	Pure	39.1	53.3	52.6	35.8	-17.6
	M. dominant	11.0	12.7	12.8	7.6.	-5.1
	M. dominated	24.0	26.5	25.8	18.9	-7.6

Data source: 6th National Forest Inventory, Final Report, 2015

The main multidimensional factors of this reduction are related to the loss of economic attractiveness of many of the micro and medium forest stands. The pine forest is one of the main components of the small Portuguese forest properties, where the degree of associative organization is too weak to promote the active management of the pine forest on a significant scale; the fires, for various reasons, namely those related to the structural causes aggravated by the maladjustment of the heritage law, reached the maritime pine forest in a massive way, far beyond the rhythm of new afforestation and regeneration of the species; the ageing of the working population and its low technical training, adding to the fragility of the support services for the farmer that do not respond to this degradation of this important natural asset.

Table 19 – Typology of the Portuguese forests and percentages covered areas (2015)

Species	Structure of forest stands			Percentage per covered area			
	Composition	Nº of trees ha-1	Basal area (m2/ha	Juveniles Without covered %	Sparse forest 10-30%	Open forest 30-50%	Dense forest ≥50%
Maritime pine	Pure	485	12.91	4.7	57.1	100.3	345.1
	M. dominant	297	10.67	0.2	8.0	20.0	79.1
	M. dominated	129	4.49	0.1	8.5	17.0	60.1
Eucalyptus	Pure	739	6.96	20.6	88.1	159.3	420.7
	M. dominant	547	7.95	0.4	4.8	14.4	58.5
	M. dominated	234	4.04	0.2	2.9	8.9	40.5
Cork oak	Pure	78	4.87	14.7	331.7	243.7	68.0
	M. dominant	65	3.94	0.8	21.4	18.9	5.9
	M. dominated	45	2.14	0.5	16.8	14.5	6.7
Holm oak	Pure	42	3.48	0.5	233.9	84.9	9.3
	M. dominant	42	2.99	0.1	6.9	4.9	1.5
	M. dominated	25	1.17	0.7	7.8	5.5	1.7
Other oaks	Pure	411	7.85	0.3	6.1	9.9	33.9
	M. dominant	262	5.53	0.0	1.2	4.1	21.3
	M. dominated	122	2.59	0.1	0.9	2.6	10.4
Stone pine	Pure	127	4.73	2.9	83.1	47.3	26.6
	M. dominant	64	4.51	0.3	12.0	11.1	5.8
	M. dominated	19	1.86	0.1	10.9	10.9	4.4
Chestnut	Pure	221	10.90	4.9	7.3	13.9	17.3
	M. dominant	367	15.58	0.1	0.4	0.9	1.9
	M. dominated	111	6.30	0.0	0.3	0.7	1.9
Carob tree	Pure	67	2.94	0.1	13.6	0.9	0.1
	M. dominant	*	*	0.0	1.5	0.2	0.0
	M. dominated	*	*	-	-	-	-

Table 19 - Typology of the Portuguese forests and percent. covered areas (continuation)

Acacia	Pure	547	6.37	0.0	0.0	0.2	4.6
	M. dominant	441	5.14	0.0	0.1	0.3	2.8
	M. dominated	219	2.95	0.1	0.1	0.9	7.2
Other hardwoods	Pure	259	5.54	0.7	20.1	26.3	88.9
	M. dominant	156	3.52	0.0	2.5	7.8	32.5
	M. dominated	106	2.17	0.1	9.8	18.1	69.0
Other softwoods	Pure	455	14.26	1.1	6.9	8.1	19.7
	M. dominant	200	6.72	0.0	1.0	1.7	4.9
	M. dominated	128	3.59	0.1	1.5	5.2	12.1

*Unrepresentative statistic; Source: 6th National Forest Inventory, Final Report, 2015

In addition to the aforementioned structural reasons, it should also be mentioned for this significant retraction of the maritime pine area, the strong disturbances to which it was subject, either because of the violent forest fires of the last two decades (more than 2.8 million ha covered by fires in the period 1990-2015) and by the occurrence of pests such as the pine nematode that has severely affected the maritime pine forest.

Concerning eucalyptus, a newcomer introduced in Portugal circa 1952 or 1954. E. globulus is practically the only eucalyptus species planted in the Iberian Peninsula. It is a fast-growing species, cultivated in a coppicing regime in short rotations (10-15 years) and has an excellent aptitude for producing high-quality paper. Growth rates vary significantly with climate and soil conditions, reaching 15 m3ha^{-1}year^{-1} in the most favourable regions, such as the coast in the centre and north of the country. It is believed that, as a genetic improvement, it can reach yields of around 30 m^3 ha^{-1}year^{-1}. The last forest survey shows that the eucalypt area reached 845,000 ha (26.2 % of the forest area) and increased by 59,100 ha from 2005-2015.

Much of the area of E. globulus is concentrated along the coastal strip, with a width of about 65 km at altitudes below 500 m. The tertiary basins of the Tagus and Sado (concentrates 65% of the eucalyptus area to the South of the Tagus) and in the mountainous regions of the South, due to a more significant Atlantic influence, a fact that combined with more favourable soils allowed a greater penetration of the culture of this species further inland. A larger area of eucalyptus in the central region results from better and broader ecological conditions favourable to the culture. One should note that the cultivation of E. globulus is decreasing from the North, with more rainfall to the South due to the decrease in the average annual precipitation, except for the Serra de Monchique, in the Algarve, that benefits from the relief and proximity to the coast (Goes[453], 1991).

The increase in the area covered by eucalyptus recorded in the period 1986/92 was due not only to the better profitability of the culture as compared to pine or other natural species but also to the new afforestation carried out under the FDF and WB's Portuguese Forestry Project and the Forest Action. The increase registered in the eucalyptus grove was not always based on a distribution adequate to the quality of the sites. This fact, allied to the movements of opinion against the expansion of the species and in the absence of integrated research giving a safe answer to the political decision-maker regarding possible negative impacts of its growth, gave rise to

[453] Goes, Ernesto (1991) – Os Eucaliptos. (Ecologia, Cultura, Produções e Rentabilidade. Lisboa, Portucel, 367 pp.

separate legislation through a series of diplomas that directly (DL 173/88, DL 174/88; Ordinance 512/89) or indirectly (DL 172/88, DL 196/88, DL 274/92) established conditionalities in this domain.

These conditionalities inter-allied with the degradation of log sales prices for the industry, the smallness of many plantation plots, the ageing of the rural population and depopulation have also led to the abandonment of small field plots that were not replanted, forcing the wood pulp industry, the central processor of eucalyptus raw wood, to increase its imports of eucalyptus wood, (≈ 2 Mm^3/year) to satisfy install capacity of their mills.

The cork oak and the holm oak are the most critical tree elements of the so-called "montados"/dehesa, a traditional agricultural system of the Mediterranean rainfed, where the absence of rain in the summer makes water the critical factor. The cork oak landscape is characterized by the overlapping in the same space of distinct plant structures and well separated vertically, in a composition of variable density: trees vs agricultural or forage crops, low brushwood or fallow, allowing great faunal wealth. The estimate is that more than 130 species of vertebrates reproduce in the mesostructured cork oak and holm oak forests, of which at least 60-75 are birds, 18-28 are mammals, 10-15 are reptiles and 5-7 are amphibians. The cork oak forest also offers various cultural amenities (recreational and leisure activities, regional identity, and aesthetic appreciation).

From an agrological point of view, the most important patches of cork oak are found in soils designated in the soil map of Portugal (1949) as podzolized sand (Pliocene formations) and sandstones originated in Miocene formations. They also occur in extensive patches of brown Alentejo soils, thin red soils from schists, and brown soils of Alentejo of granite origin. Thanks to its plasticity, cork oak appears in practically all types of soils in the national territory, except for calcareous or excessively clayey soils.

Regarding climatic distribution, the cork oak also presents remarkable plasticity, distributed in an area with rainfall between 600-800 mm, an aridity index of 1.8-2.8 and absolute thermal minimums not lower than -5ºC. The tolerance regarding rainfall is great as it grows in good conditions in the Northwest of the country, where the average annual rainfall is nearly 2,000 mm. In fact, only the minimum winter temperatures below -5 ºC, which in Portugal are only registered in the mountainous regions of the North, and the low rainfall in the Southeast Alentejo restrict the cork oak in some Portuguese ecological zones. The most prominent patches of cork oak, where it grows with good vegetative vigour, are found in the transition zone from the climate with Atlantic characteristics in the so-called western Mediterranean region, where the influx of the Atlantic winds corrects the great amplitude of the thermal oscillations and the high summer aridity of the typical Mediterranean climate.

The components of the assembled "Montado" system are quantitatively integrated in a very variable way, providing forms of land occupation of the agroforestry, silvo-pastoral or agro-silvo-pastoral type. Crops filled the herbaceous component of these systems for grain, in some cases integrated into a legume-cereal-fallow rotation, in others only cereal-fallow. The more or less long fallows provided grazing from the cereal stubbles by sheep. In this system, cork and holm oaks constitute the two distinctive tree elements with an artificial park-like structure of high value regarding ecological and landscape diversity. It is also a distinctive feature of the form as the farmer combines different ways of using the land and the resources of the other factors of production to obtain certain types of forest products, vegetables, and animal goods. Thus, "montados" have some characteristics of their own:

- They are agro-silvo-pastoral systems, with the particularity that the tree component is constituted by more or less open stands of cork oaks and holm oaks and, in small scales, by other oaks.
- Are anthropic systems that, in a particular historical period, acted in the natural environment, aiming to create tree stands to take advantage of certain specific goods originating from tree resources (fruits and/or bark) or agriculture (pasture, forage crops and wheat fields).
- They are dynamic systems, since having been created by man based on economic interest, any fluctuations that occur in the levels of returns on the goods obtained cause changes in the intensity of use of resources or even their abandonment (as in the case of the mountain pig, which due to the African swine fever led to the abandonment of the holm oak forest in the past five decades, although there is currently a somewhat slow recovery in this use).

Throughout the 20th century, the primary productive orientation in these systems has varied, "*dominating in some phases the intercropping with cereal farming and cattle raising, namely in the holm oak forests, noting in other stages, as at present, a movement of abandonment cereal grain, which is being replaced by cattle raising associated with the establishment of improved pastures and other forage crops*" (Coelho[454], 1994).

As shown by the history of land cover in Alentejo, the formation of modern "montados" in Portugal resulted from the transformation of natural arboreal and shrubby formations through the selection and promotion of the predominant woody species, the cork oak (and to a lesser extent *Quercus pyrenaica*) in the climatic sub-zones with Atlantic influence and the holm oak in the drier and interior with more continental influence, simultaneously with the use of the soil for agricultural and livestock purposes.

A brief revision of men's influence in the current situation of montados reveals that the vegetation cover in the Alentejo between the 12th and 18th centuries, and particularly during the reigns of D. João II and D. Manuel I, there was a significant regression of cork oaks, holm oaks and other forests in the south of the country as a result of the increase in population and the needs of agricultural promotion, the decline of "montados" and the abolition of game reserves, the cutting of firewood and wood, the harvesting of acorns, and cork, and also the needs of shipbuilding (Natividade[455], 1950). Despite some protectionist countermeasures enacted by the crown to try to minimize the then worrying dilapidation of the forests, in the 18th century, the forest area was reduced to half of what existed in the 12th century, which, for, in turn, it would already be a weak image of the area that existed in the beginnings of the nationality (Rebelo da Silva quoted in Natividade, 1950). At the origin of the 18th century and until the beginning of the 19th century, about two-thirds and half of the Alentejo was in the bush, consisting of thickets of cork oaks and holm oaks, with the heaths covered by rockrose and heather (Radich and Alves, 2000).

As early as 1790, Sequeira (quoted by Natividade, 1950) defended the importance of the cork oak. However, cork did not then have the significance and functions that are recognized today: "*the bark stripped from the cork oak, for the tanning of the leathers, its corks are also used a lot in the economy, now to make the bee slums, now to cover the corrals, and finally for many other important uses*". Although there was already some recognition of the value of the cork oak at that time, it is

---

[454] Seita Coelho, I. (1994) – Economia do Montado II. Análise Económica de Três Montados de Sobro Alentejanos. *Silva Lusitana*, Ano II, Vol 2, 2:133-141.

[455] Natividade, J. Vieira (1950), *Subericultura*, 2.ª edição, Lisboa, Direcção-Geral das Florestas, 449 pp.

interesting to note that the botanist Link visiting Portugal (1805) states that "... *the province of Alentejo is generally so uniform that it is easy to describe it. The plains are sandy and covered with maritime pine forests, heaths, and cysts*". In his words (cit. by Belo[456], et al.,2009) "… *most of the province is formed by hills and mountains of clad sandstone, covered with rockrose, which makes it an arid and uniform desert, occupies the place of the forest in this region because it provides firewood and charcoal*". This botanist, in his long travels through the Alentejo, only mentions the existence of cork oaks and holm oaks in Palma, along the river Sado, along Serpa and Portalegre and on the way from Évora to Montemor.

In this period, which coincided with the beginning of the Liberal Regime, a set of conditions was met that allowed the creation and development of the montados. The necessary conditions were: i) the acknowledgement of full private property; ii) the predominance of large to vast estates, iii) the availability of abundant and cheap wage labour; iv) the emergence and sustained increase in demand in the national and international market for specific cork oak forest goods, such as Alentejo pork and cork, and the emergence of favourable conditions for triggering the cutting of thickets and the clearing of the soil.

Unleashing a process of clearing extensive areas implies substantial investments that can only be carried out under favourable conditions. As there were initially no specific policies to support the clearings and the formation of cork oak forests, the promotion of wheat cultivation led to the outbreak of land clearings. Then, for about a century and a half, the bush clearings increased, stimulated by protectionist policies and the promotion of wheat cultivation, namely the Laws of Elvino de Brito (quoted by Picão[457], 1983), in the late 19th century, as mentioned by Anselmo de Andrade, and the famous "Wheat Campaigns" in the late 20s of the last century. The demand for specific products from the montado began with the Alentejo pig breed. In the 18th century, fat pig meat was one of the main exported products. This period was a decisive time for the expansion and economic sustainability of the Holm oak forests.

As stated in 1948 by Garcia (quoted by Belo et al., 2009), the cork business came later and expanded more slowly, "*the appreciation of the cork oak was very recent throughout the country*". This farmer from Couço, responsible for managing his agricultural properties in the municipality of Coruche from 1916 onwards, wrote a monography about his parish on the valorisation of cork that, according to his report, has completely changed the treatment of these vast areas. Soil clearing began with the uprooting of all species competing with cork oaks, which he stated: "*Workers in sparsely populated parishes were not enough to clean quickly so many hectares of forests (bushes full of wolves, wild boars, lynxes, foxes, and thousands of rabbits) and the owners and tenants call groups of workers from Beira, with whom which during the winter did the grubbing*".

Figure 38 depicts the evolution of the cork oak area in the three districts of Alentejo. In 1852 the tiny area tripled between 1852 and 1875 and grew more than double between 1875 and 1980. In less than a century and a half, the size of cork oak forests increased more than seven times.

Until the last survey (2015), it was represented in an area of 719,900 ha consisting of pure stands, mixed dominant and dominated and dispersed trees primarily located in the districts of Santarém and south of the Tagus and the districts of Castelo Branco and Bragança. The country's largest patch of the cork oak is concentrated on the south bank of the tertiary basin of the Tagus River, constituting almost a continuous population, in most cases only interrupted by agricultural

---

456 Belo, C. Carmona, Pereira, M. Silva, Moreira, A.C., Coelho, I. Seita, Onofre, N., Paulo, Ana A (2009), Capítulo 8, Montados, pp 251-293, in: (eds) Luís Vicente, Vânia Proença, Tiago Domingues e Henrique Pereira, *Ecossistemas e Bem-Estar Humano em Portugal*. Escolar Ed., 730 pp.

457 Picão, J. S. (1983) - *Através dos campos,* Lisboa, Publicações D. Quixote.

land in alluvial trenches on the banks of the Tagus River and its tributaries. The cork forests are still well-preserved in Ponte do Sôr, Abrantes, Chamusca, Coruche, Benavente, Mora and Avis, with cork considered of exceptional quality. The country's cork oak patch, in terms of size and quality, is undoubtedly that of the Serra de Grândola on schist land; also worth mentioning are the patches of Montado in the Monfurado mountain range and the Serra do Caldeirão in the centre of Barranco Velho.

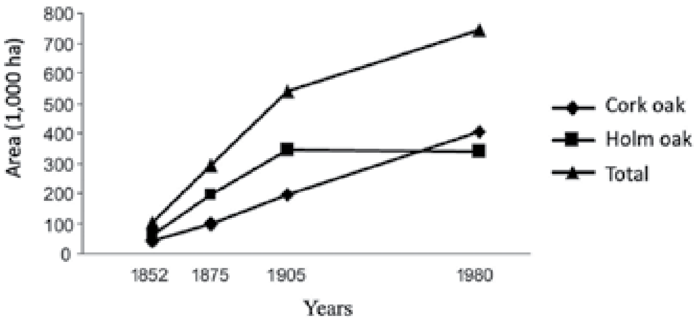


Fig. 38 - Evolution of the Montado area in Alentejo
Source: Coelho[458], 2005

North of the Tagus River, the cork oak occurs in small nuclei in the interior, with a climate where the Mediterranean influence is felt at altitude, as in Castelo Branco, Idanha-a-Nova and Penamancor.

In the ecological zone, where continentality neutralizes the Mediterranean influence, the cork oak usually grows in association with the holm oak.

The models of occupation of the space in which the cork oak participates can cover various forms of land use and tree management, from the extreme stand of park type, with relatively high density and in which the replacement of the senile trees is duly addressed with the permanent pasture or in rotation with crops or other forest crops such as strawberry tree under cover and even in some cases with pine as a way to ensure some intermediate income and to pave the way for a final stand only of cork oaks. There are still more conservative forms of exploitation to be distinguished in those spots where the under-covered vegetation is spontaneous, the so-called cork oaks, which distinguish them from the cork oak forests where the under-cover is an agricultural crop (cereal or pasture). From the view of the vitality of these two forms of land occupation and the integrity of ecological systems, it is easy to see that the manifestations of decrepitude and health status are more pronounced in the "montados".

Since the mid-twentieth century, with the decisive abandonment of cereal crops and the production of free grazing pigs due to swine fever and more recently with the increase in the presence of cattle and currently with the robust expansion of intensive olive and almond groves, witnessed a significant retraction of the area of cork oak and the abandonment of the less productive areas that have been, even due to the reduced natural regeneration observed, covered by shrubby vegetation more susceptible to fire.

[458] Coelho, I. Seita (2005) – Cork oak woodlands raw material products for industry: historical survey, Conference SUBERWOOD, Huelva, Espanha.

Extensive agriculture practised in cork oak forests requires practices that integrate environmental diversity, considering the sustainability and multi-functionality of the ecosystem. To maintain the ecological importance of the cork oak forest and guarantee its environmental and recreational services, the farmer must be encouraged to adopt sustainable exploitation certification practices and mitigate measures financed by the values of the ecological goods generated.

The cork oak and holm oak stands denote an advanced age, a low density, and a worrying incidence of pests. In open areas already with low tree densities, installations by sowing or planting did not compensate for the decrease in the stands. The regeneration and survival of cork oak seedlings in the spring are particularly difficult in the interior areas due to the scarcity of water and the irregularity of rainfall, which has been happening more frequently lately. It is also worth mentioning that the water efficiency in eroded and skeletal soils is significantly lower. In many cases, insufficient regeneration is also due to excessive cattle loading. The decline and death of the cork and the holm oaks are problems that mainly affect the stands in the centre and south of the country.

The state of degradation of the cork oak forest is a reality that has been increasing in the last 50 years in almost the entire area of distribution of this ecosystem, with symptoms practically common to those observed worldwide for other oaks. Among us, there are even older references to occurrences of mortality outbreaks at least since the end of the last century by researchers such as Veríssimo de Almeida and Câmara Pestana and since then, especially in periods of severe drought (1943-45, 1975-76, 1980-83). Most of the causal studies on cork oak mortality were focused on the search for biotic factors in line with the work initiated by Lopes Pimentel[459] (1946), who identified the Phytophthora cinnamomi that attacks the root system of trees. The same fungus was identified by Brasier[460] et al. (1992). Different was the approach of an integrated study by a multidisciplinary team led by the National Forestry Station (Cabral, et al., 1992), which concluded that mortality seemed to be rooted in a complex of intertwined and inter-acting causes, the analysis of which was not likely to be elucidated in a segmented way.

The study in reference allowed the following conclusions:

a) Factors that predispose

In this cluster, the coincidence of divergent or at least different interests on the same land (on the one hand, the owner of the land and on the other, the tenant exploiting the agricultural crop) duality of entities that use the ecosystem stood out. The image of the interface between the production and social systems reveals discrepancies that help explain the worsening of mortality "... we found that man and trees are unfortunately poorly synchronized with each other" (Hvass[461], 1990). Indeed, in a multiple-use system, the intensity of use of each user must be synchronized to maximize the overall sustained performance of the system.

b) The physical system

The cork oak in the "montado" grows in areas with distinct edaphic and microclimatic characteristics, which are irregular and often subject to severe droughts. In this context, local

---

[459] Lopes Pimentel, A.A. (1946) – O sobreiro também é parasitado pela *Phytophthora cambivora* (Petri) Buis, agente da "doença da tinta" do castanheiro, Lisboa: Public. Dir. Ger. Serv. Flor. e Aquic., 13: 45-49

[460] Brasier, C.M., Moreira, A.C, Ferraz, J.F. e Kirk, S (1992) – High mortality of cork oak in Portugal associated with *Phytophthora cinnamomi*, pp 461-462. In: Proceedings of the international Congress "Recent Advances in Studies on Oak Decline. IUFRO, Selva di Fasano (Brindisi), Itália, 13-19 Setembro

[461] Hvass, M. (1990) – Análise dos sistemas de exploração do montado de sobro no Alentejo. EFN, Lisboa, 45 pp

situations make the species more sensitive to local conditions of growth or degradation (*solana* and *umbria*). The physical environment, worsened by degrading agricultural practices, is also characterized by less resilience to incorrect management practices. Mortality peaks are, therefore, more pronounced in periods of drought. The data revealed that:

- There is a positive correlation between the physical and morphological characteristics of the soil and the vegetative state of the cork oak.
- Where the degree of aeration and infiltration capacity is affected, thanks to human intervention (inadequate cultural operations, excessive trampling, and soil compaction), the decrepitude of the cork oak forest is evident, and mortality is accentuated.
- In valley forms, constraints on the vegetative development of the cork oak seem to be related to the persistence of lateral and subsurface aquifer runoff flows. If they occur for an excessively prolonged period, especially in hillside valleys, especially when very open, the frequency of dead cork oaks is more pronounced.
- In the wavy relief forms and pronounced slopes towards the valleys, in general, relating to light, deep soils with good permeability, the vitality of the cork oak and its large size stands out, a reflection of a favourable edaphic-morphological environment and hence the absence of manifestations of decrepitude or mortality.
- In lightened, podzolized, well-drained soils with a very porous coarse sandstone substrate and any morphological situation, the cork oak is generally unaffected, being able to freely expand its root system, provided that it is not affected by heavy ploughing.
- In medium/thin or thin schist soils, in pronounced wavy relief forms, generally uncultivated, in understory with varied floristic composition, the cork oaks behave despite their small size satisfactorily. However, there are differences in the vegetative strength between the north-facing and south-facing cork oaks.
- In clay-alluvial schist soils, in correspondence with broad and more or less smoothed wavy relief, the aspects inherent to the permeability of the profile and the degree of aeration start to become volatile. Their aggravation, potentiated by more intense bouts of dryness or unadvised soil management interventions, is likely to potentiate outbreaks of pathogens and consequent mortality.
- In red soils, related to "*raña*" deposits with worse aeration conditions and slow permeability, generally identified with gently undulating or flattened reliefs, subject to more or less intense agricultural or livestock occupation (cereal and agropastoral farming), the cork oak is progressively marginalized and abandoned. This is where the most significant patches are found with a higher incidence of dead cork oaks and a strong presence of pathogens and insects wherever they occur.
- There are even more severe situations in which the death of cork oaks is almost widespread. Such cases are recognized because they are generally identified with patches of clayey-alluvial or parahydromorphic soils or flatlands, where trees remain in precarious balance with the environment. Here, any anthropocentric interventions or disturbances resulting from prolonged droughts or floods worsened soil aeration or moisture conditions, leading to the death of cork oaks.

c) Production system

Observational field data shows that incorrect ecosystem management is mainly responsible for the current degradation that the montados have reached in southern Portugal. In fact", in this type of multiple exploitations typical of the "montado", it is challenging to reconcile the various productions, especially as verified in the project's areas of incidence, land leasing systems prevail for agriculture or pastoralism without considering the impact of these operations on cork production. In this component, the following predisposing practices were detected: i) lack of continuity of actions or mitigating measures in terms of technical interventions (in agricultural systems and tree management control); ii) the wheat crop, which is primarily maintained in shale areas on flat surfaces or with little expressive relief, using mechanized cultivation operations; iii) persistent and excessive concentration of cattle, as occurs in overnight or watering areas subject to heavy trampling and the consequent lack of soil aeration.

d) Trigger factors

As previously mentioned, the study of climatic variations and prolonged droughts demonstrated parallel occlusions of abnormal cork oak mortality. This synchrony was also mentioned by Montoya[462] (1995) but its direct correlation must be viewed with caution since it is highly dependent on anthropogenic factors, as mentioned:

• Form and intensity of exploitation. The intensity of stripping proved to be an aggravating factor in mortality. Indeed, significantly higher mortality was found when it reached the crown Level 3).

• Understory management. Cork oak phytocenoses are generally of anthropic origin, varying their degree of degradation about the climax, according to the use of the soil and the intensity of disturbances in the ecosystem. If we bear in mind that under natural conditions, there is a recycling of nutrients via three primary decomposition-absorption cycles: a rapid one via herbaceous vegetation, one of intermediate duration through the bushes, and another slow on the part of trees that retain nutrients for a longer time and make them available very slowly (leaf), we found the explanation as the type of intervention, intensity and frequency in the management of the undercover intervene in the process of gradual depletion of the bottom of soil fertility. The removal or cutting of the strata corresponding to the fast and intermediate cycles leads to a loss of nutrients instantly released by decomposition and quickly leached. Field data show that as frequent undergrowth cutting persists to manage the Montado and as one descends in the *sigmentum*, from the climax to the most degraded stages, an increase in mortality intensity is verified.

e) Accelerating factors

It was also shown that there was a relationship between the lack of regeneration and mortality, seeming to show poor management of the use of the undercover soil. Total soil cleaning interventions instituted, even in cases where this type of soil intervention is not intended for subsequent agricultural use, prove to be harmful to the recovery of the ecosystem.

In brief, the integrated approach of the different causes and respective ecological contexts and human intervention that condition the decline of the cork oak forest and the occurrence of greater or lesser mortality in Portugal showed that thin soils with a fine texture, high clay and silt contents, and low phosphorus and nitrogen contents are more associated with the disease. Also, places with poor drainage and slopes exposed to the south offer a greater risk of illness or pest incidence in mature and young trees. Intensive agriculture practices involving frequent soil ploughing showed their harmful effect on the tree root system, making it more prone to fungus

---

[462] Montoya Olivier, J.M. (1995) – Efecto del cambio climático sobre los ecosistemas forestales españoles. *Cadernos da la Sociedad española de Ciencias Forestales*, Nº 2: 65-76

infection. The soil pathogenic fungus *Phytophthora cinnamomi* and some agriculture practices threaten the success of natural regeneration and the establishment of new stands of cork and holm oak through direct sowing and, consequently, the survival of these species.

Despite its economic importance for the agricultural sector's trade balance, its area has almost continuously decreased, reaching 11,900 ha in 2005-2015. It is the abandonment of regions affected by decrepitude or diseases and the replacement of this species by eucalyptus cultivation, as can be seen a little everywhere, but more pronounced in the districts of Castelo Branco, Portalegre and Santarém or, lately, by intensive cultivation of olive oil or almond plantations in Alentejo.

Although the cork oak has benefited from the European program for the afforestation of agricultural land and the law for the protection of cork oaks (Decree-Law nº 169/2001 with the amendments introduced in 2004), which penalizes abandonment and operations that damage the trees and which establishes that felling is only possible with authorization from the National Forestry Authority, the fact is that these measures or the effectiveness of the instruments made available to the owners have not been sufficient to prevent the retraction of the cork oak forest area at a high pace.

Current changes in land use and the substitution of significant areas of Montado with intensive olive and almond orchards are of great concern. One should not forget that agricultural diversification is critical to achieving climatic resilience (Campbell[463] et al. 2014; Cohn[464] et al. 2017). Crop diversification is one important adaptation option to progressive climate change (Vermeulen[465] et al. 2012) and it can improve resilience by engendering a more remarkable ability to suppress pest outbreaks and dampen pathogen transmission, as well as by buffering crop production from the effects of more significant climate variability and extreme events (Lin[466] 2011).

It is worth remembering that the environmental sensibility of this ecosystem requires particular attention, as the preparatory field team of the WB Forest Project[467] (1983) wrote many years ago: "*The insufficiency of detailed data and information was a severe constraint to formulating a long-term strategy for developing the cork oak forest, which is deemed essential to securing the medium to long-term needs of the resource management there, including needed ecological mitigation measures and associated industrial development*".

The holm oak (*Quercus rotundifolia*) is another of the Mediterranean oaks that is a dominant species in the southern interior of the country, where it grows "*thanks to its ability, demonstrated*

---

[463] Campbell, B.M., Thornton, P., Zougmoré, R., Van Asten, P. and Lipper, L. (2014) - Sustainable intensification: What is its role in climate smart agriculture? *Curr. Opin. Environ. Sustain.*, 8, 3943.

[464] Cohn, A.S., Newton, P., Gil, J.D.B., Kuhl, L., Samberg, L., Ricciard, V. Manly, J.R., Northrop, S. (2017) - Smallholder agriculture and climate change. *Annu. Rev. Environ. Resour.*, 42: 347–375.

[465] Vermeulen, SJ., Aggarwal, PK., Ainslie, A., Angelone, C., Campbell, BM., Challinor, AJ., Hansen., JW., Ingram, JSI., Jarvis, A., Kristjanson, P., Lau, C., Nelson, GC., Thornton, P.K., Wollenberg, E. (2012) - Options for support to agriculture and food security under climate change. *Environ. Sci. Policy*, 15: 136–144.

[466] Lin, B.B., (2011) - Resilience in agriculture through crop diversification: Adaptive management for environmental change. *Bioscience*, 61: 183–193.

[467] Portugal. The Cork Oak Forest. Important Issues Relating to the Future Development of the Resource. Field Document Nº 18, UTF/POR/001/POR, FAO/WB, 31 pp.

over the centuries, to resist cultivation under cover, destruction by fire for the installation of pastures and the very grazing" Bugalho[468] et al., 1994).

The species supports very degraded sites with impoverished and skeletal soils, preferring, however, the Mediterranean red groups' soils vegetating well, contrary to the cork oak, in calcareous soils. Holm oak "montados" are also the result of long human intervention in the ecosystem.

In the 1980s, Holm oak covered 604,800 ha in Portugal, of which 464,700 ha were in pure and mixed stands. Of this area, 69.7% were in the districts of Évora and Beja. Currently (2015), the pure dominant and mixed dominant stands are reduced to 341,800 ha. This reduction means that the holm oak area has been shrinking by an average of 8,200 ha/year, which is quite worrying in such a sensitive ecological area.

This reduction in area was mainly due to the decline in free-grazing pig farming (*montanheira*), fed on the holm oak acorns. With the pig crisis, other activities replaced it, such as rainfed arable crops under cover, cereals, and eucalyptus in other more humid sites. Understandably, the undercrowded stands were the ones most sacrificed by the expansion of rainfed arable crops to allow for easier mechanization of crops and harvests. These areas are primarily in marginal land use classes for agriculture, where their viability was only possible through subsidizing the prices of products and with intense interventions with severe pruning of the holm oaks for the sale of firewood and charcoal. This type of intervention has left a very marked negative impact both in the increase in the mortality of the trees and the growth in the degradation and aridity of the regions of the Southeast of Alentejo.

However, it cannot be forgotten that while the decline in the Holm oak forest was related to the abandonment of free-grazing pig farming in the 1960s, there was also an expansion in Portugal of intensive animal husbandry significantly based on imported rations. Administrative intervention to face this regression (Decree Law Nº 227/84) has proved to be ineffective because the fines were not dissuasive and did not attack, as Rosário[469] et al., 1986 mention, the structural factors "... *the problem of depressed or pre-desert regions, ranging from the accentuation of rigorous soil and climatic conditions to the growth of poverty and human desertification, to ignorance, distancing or deliberate abandonment on the part of the State apparatus that result in the lack of ecological, economic and social incentives and the lack of adequate institutional solutions*".

With the eradication of African swine fever in the early 1990s, the authorities and Community legislation supporting the afforestation of around 20,000 ha of holm oaks "montados" (Reg. (EEC) No. 2080/92) and the CAP reform of 1992 eliminating the support policy for cereal production, as well as Decree-Law No. 431/93 that created the denomination of origin and the demarcated region of "Presunto de Barrancos [Barrancos Ham]" increased the area covered between the 2005 and 2015 censuses in the order of 13,700 ha, even so below the target of 20,000 ha of the projects approved in 1994/95 under Reg. (EEC) mentioned above.

With economic significance, we must refer to some agroforestry systems cultivated for producing fruits intended for human consumption and where the livestock component has a secondary role. They are the chestnut orchards with the most significant expression in the

---

[468] Bugalho, J., Carvalho, C.R., Alves, R., Simões, H. (1994) – Zona Agrária de Aljustrel – Estudo de Ordenamento Agrícola e Florestal – Vol 5 – Silvicultura, Lisboa, ERENA.

[469] Rosário, Lúcio Pires do, Cabral, Maria T., Onofre, Nuno R. (1986) – Sobre a Azinheira – Quercus rotundifólia - em Portugal. Importância e necessidade da sua conservação. Comunicação apresentada no 1º Congresso Florestal Nacional, Lisboa, 2-6 de Dezembro de 1986

Northeast of Trás-os-Montes and the stone pine groves in the Algarve's Barrocal region, most often accompanied by carob and almond crops.

In the last survey (2015), the chestnut area reached 48,300 ha, increasing from 2005 to 2015 by 13,900 ha. More than half of this area comprises chestnut trees grafted for fruit production. This zone is concentrated in the cold zones between 600 and 900 m in altitude, in the North and Interior Centre, namely in the municipalities of Vinhais, Bragança, Valpaços, Resende, Sernacelhe and Penedondo. Although with less expression, we must mention the Portalegre and Beira Interior areas. These areas to which chestnut cultivation is limited today present conditions less favourable to the proliferation of the "ink disease", which, since 1838, began to decimate chestnut trees in Portugal, especially those on the North Coast.

The main ecological-cultural parameters for chestnut cultivation (Monteiro Alves[470], 1982) are: average annual temperature of 9 to 14 ºC; annual average precipitation from 800 to 1600 mm; average temperature of the coldest month greater than -1 °C; absolute minimum temperature above -15°C. Concerning soils, there is an excellent adaptation to the different soil types. However, it prefers siliceous soils and those of calcareous origin already decalcified, always fresh and with some depth.

The Chestnut Distribution Chart published by SROA (1951/1953) mentions 51,000 ha of pure stands and 33,339 ha of mixed stands. Carqueja[471] et al. (1996) justify such a high reduction in the area of chestnut trees in comparison to the current one due to the "*converging influence of economic causes - chestnut wood is very well paid for carpentry; social factors, such as the sharp decrease in the active population in traditional areas of implantation of the crop, and also Phyto-pathological causes, namely the incidence of ink disease and, more recently, cancer*".

In Portugal, two systems of exploitation are distinguished according to the objectives pursued: the production of fruits and the production of wood. Thus, "soutos" are those plantations of the so-called tame chestnut trees, that is, those chestnut trees grafted at 3-4 years of age and intended for fruit production. If no problem destroys it, this chestnut tree can reach a very high longevity. Grafting is almost always done in a nursery or after planting. The technique of vegetative multiplication is also used from selected native chestnut trees or hybrids of native chestnut X Japanese chestnut that have proven resistance to ink disease and are fruit producers with high commercial value. A "*souto*" with normal density and in full production can produce 2000 to 4500 kg of chestnuts per hectare. When the objective is wood production under a high stem or coppice regime, it is called "*castinçal*".

Since 1980, there has been a progressive increase in the area of chestnut trees, which is explained, among other reasons, by the valorisation of the fruit about other production options that adapt to the same ecological conditions, namely seed potatoes and rye. Furthermore, it should be noted that the fruit is a relatively quickly merchantable product on the international market.

In addition to the factors mentioned, which reflect the importance of chestnut orchards and the reasons for the increase in area of around 10,000 ha between 2005 and 2015, the positive reception rural people give to chestnuts should be mentioned. In addition to the indicated drivers that reflect the appreciation of the rural population, Carqueja et al. (1996) say that "*Not only the elderly but also multi-active absentees and landowners love chestnut orchards. This land legacy is equally*

---

[470] Monteiro Alves, A. A. (1982) – Técnicas de Produção Florestal, Lisboa, INIC, 311 pp.

[471] Carqueja, L., Rocha, J., Portela, J. & Portela Ester (1996) – Da Importância do Castanheiro na Serra da Padrela – Estudo de Caso em Redondo, UTAD, Abril.

valued by other newer actors who are more dependent on agriculture. All of them do not want to see their land abandoned, and they see the chestnut tree as a way to avoid such a situation."

We must not forget the central habits and traditions of the use of chestnut trees in poor areas, as stated by Burgeois[472] (1993) and which have served as a mainstay for the maintenance of this species that "*has profoundly marked, for centuries, the economic and daily life of regions where the culture of cereals was difficult (acidic and poor soils), creating a true "civilization" whose signs can be recognized from Brittany to Galicia, from Trás-os-Montes to Tuscany*".

Concerning stone pine, the species occupies (2015) an area of 193,000 ha, showing an increase of 20,700 ha from 2005-2015. The stone pine is a thermophilic and heliophile species, withstanding not very intense cold and appreciable dryness but requiring average temperatures above 10-11 ºC. It thrives in areas of annual rainfall between 400-800 mm, which, in Portugal, already correspond to situations of marked dryness, namely in the summer period. It prefers light or sandy and cool terrains but adapts well to other types, including moderately calcareous ones (Monteiro Alves, 1982). Its distribution area is located mainly in the municipalities of Álcacer do Sal and Grândola and Montemor-o-Novo, Coruche and Benavente, which produce more than 80% of the pine nuts sold.

The increase in the area covered by stone pine (73,400 ha) in the period 1995-2015 was achieved through spontaneous repopulation, along with the plantations supported by the former Forest Development Fund and the support given to it by a productivity breeding program and grafting with selected clones. The main drive for this development was the significant increase in the value of the kernels in the national and international markets. It should be noted that while in 1970 Portugal exported 23.3 t of kernels and 4.5 t of pine nuts in shell, 1986 reached an export volume of 658.6 t of kernels and 43.5 t of pine nuts in shell, which was possible with the renovation and re-equipment of the national pine nut shelling industry located in the municipalities of Alcácer do Sal, Vendas Novas and Grândola.

In the last 20 years and thanks to the strong appreciation of the fruit and the high plasticity of the species to aridity and light and dry soils, there has been a substantial increase in the area of stone pine orchards, which from 2009 to 2019 had a growth of 154,1%. In 2019, 5,792 stone pine farms were registered for fruit production, with a strong predominance of the rural regions of Beira Litoral, Ribatejo e Oeste, Alentejo and Algarve, where the variation in the number of farms in that time interval presented highly expressive of 1111%, 1944%, 1589% and 576%, respectively.

Concerning the other species listed in Table 17, totalling 267,200 ha (≈8.3%) of the total forest area, some native and others exotic, even from ecological zones close to the Portuguese ones, it can be said that their persistence in the landscape remains static. This is mainly due to its modest economic or ornamental value since even, in this case, its use is confined to little more than botanical gardens, some private gardens, or a few urban streets. When there is no good correlation between the amount of potential supply, wood quality and industrial capacity, the probability of failure is almost always inevitable. It does not seem to us, therefore, to be expected that these species, even concerning native hardwoods such as oaks, whose promotion has been heavily promoted, will have an increase in expression in the Portuguese forest. The structure and tenure of the majority of the forest area and the economy are not in such a way as to favour them.

---

[472] Bourgeois, C. (1993) – Aspectos Técnico-Económicos do Castanheiro Florestal, Sociedade e Território, 19: 8-12.

6.2.1.3 – Property regime and cadastre

The land structure in Portugal is marked by the property's dispersion, fragmentation, and small size, particularly in the area north of the Tagus River. It presents structural deficiencies that compromise the viability and economic sustainability of the farms, leading to the abandonment of agriculture and areas without management of woods and forests. The ageing population and increasing abandonment trends in rural areas aggravate this context of retraction of traditional activities.

Table 20 depicts the fragmentation of the forest area by species showing the high values of the small-size classes for most species. This fragmentation, the smallness of the forest holdings, and the delay in the modernization of the regulatory inheritance law to contain continuous fragmentation are some of the great difficulties in organizing stands with adequate size to implement effective management of a substantial part of the Portuguese forest.

In Portugal, only about 3% of forest land is owned by the State (national forests) and other public entities, with the remaining area being held by local communities (the so-called Baldios), which makes up about 6%, largely subject to the mandatory partial forestry regime and 91% by private landowners (whose number amounts to several hundred thousand) with 4% managed by industrial companies (ICNF, 2021).

Table 21 depicts the structure of the private forest ownership.

The significant predominance of private forest ownership is clear, and the structures that characterize it are quite different in the North and South of Portugal.

At North of the Tagus River, the private forest is characterized by the predominance of tiny plots and by the supremacy of conifers (pine forests) and fast-growing hardwoods (eucalyptus). Its primary vocation is wood production.

At the south of the Tagus River dominates the large property, in which agricultural activities, forestry and pastoralism are often associated, and where they are predominant cork oak and holm oak. Although there is a general idea about the structures of rural property, particularly private forest property, this knowledge is superficial insofar as it is not supported by studies conducted in this direction. In a very synthetic way, Table 21 shows numbers from a survey of a sample of forest owners in representative parishes in various regions from the Portuguese mainland (Coelho[473], 2003) that help to characterize the structure of private forest ownership.

Table 20 – Total Forest areas by size classes

Area classes	[0.5;2[		[2;10[		[10;50[		≥50	
	1000 (ha)	Error (%)	1000 (ha)	Error (%)	1000 (ha)	Error (%)	1000 (ha)	Error (%)
Maritime pine	233.3	±1.9	254.2	±1.6	144.6	±1.8	81.2	±2.6
Eucalypts	220.2	±2.0	266.1	±1.8	202.9	±2.0	155.8	±2.2
Cork oak	83.6	±5.8	173.6	±3.7	209.0	±3.0	253.7	±2.3
Helm oak	25.3	±3.3	67.0	±2.3	105.4	±2.1	151.7	±1.6

[473] Coelho, I. Seita (2003) – Propriedade da Terra e Política Florestal, *Silva Lusitana* 11(2): 185-199

Table 20 – Total Forest areas by size classes (continuation)

Other oaks	26.7	±5.8	31.5	±5.4	16.4	±7.1	7.1	±8.9
Stone pine	27.0	±5.9	51.3	±4.3	59.5	±4.0	55.7	±4.0
Chestnut	26.8	±6.0	16.5	±7.6	4.6	±14.4	<0.5	>40
Carob trees	4.2	±15.0	6.5	±12.1	3.6	±16.3	2.1	±21.3
Acacia	5.4	±13.3	2.2	±20.5	0.7	±35.8	<0.5	>40
Other hardwoods	94.4	±3.1	69.9	±3.7	20.0	±6.9	5.8	±10.6
Other softwoods	16.8	±6.7	20.4	±5.7	12.2	±7.0	2.7	±12.5
Temporarily deforested surface without identified species	1.5	±16.1	1.5	±11.8	1.0	±9.6	1.6	±12.0
TOTAL	756.3	-	960.9	-	780.0	-	718.0	-

Source: 6th National Forest Inventory, Final Report], ICNF, 2015

Table 21 – Structure of private forest ownership in Portugal

NORTH								
	Dimension classes (ha)							Total
	<1	1-5	5-10	10-20	20-50	50-100	>100	
No. of private forest owners	2319	501	55	27	12	3	0	2917
No. of properties	3702	2648	632	312	86	41	0	7411
Area of forest stands	651.9	1021.1	366.3	375.1	327.7	259.0	0	3001.1
Area with bush and without forest	850.0	613.7	276.7	119.6	166.6	537.8	0	2564.4
Total forest area by classes of dimension	1501.9	1634.8	643.0	494.7	494.3	796.8	0	5565.5
%	25.1	27.3	10.7	8.3	8.3	13.3	0	93.0
CENTRE (Inland Beira and Littoral Beira)								
No. of private forest owners	5577	1299	188	69	25	4	5	7167
No. of properties	12609	12267	3819	1942	740	28	392	31797
Area of forest stands	1556.0	2795.6	1314.0	888.3	781.9	306.1	1534.8	9176.7
Area with bush and with forest (ha)	201.7	362.2	317.0	121.6	287.1	16.5	32.4	1138.5
Total forest area by classes of dimension	1757.7	3157.8	1631.0	1009.9	1069.0	322.6	1537.2	10485.2
%	16.7	29.9	15.5	9.6	10.1	3.1	14.6	99.5

Table 21 – Structure of private forest ownership in Portugal (continuation)

RIBATEJO AND WEST								
No. of private forest owners	2211	1228	232	92	188	30	54	4035
No. of properties	3633	3133	895	408	397	142	124	8732
Area of forest stands	917.8	2607.7	1624.1	1244.0	2801.5	2121.3	16298.1	27614.5
Area with bush and with forest	341.0	491.7	319.2	121.7	482.0	355.4	684.7	2795.7
Total forest area by classes of dimension	1258.8	3099.4	1943.3	1365.7	3283.5	2476.7	16982.8	
(%)	4.1	10.1	6.4	4.5	10.7	8.1	55.6	99.5
ALENTEJO								
No. of private forest owners	633	370	118	109	98	51	59	1438
No. of properties	805	650	209	232	218	78	160	2352
Area of forest stands	209.2	948.4	856.3	1514.7	2999.9	3479.9	21756.6	31765.0
Area with bush and with forest	14.7	19.6	25.0	9.3	24.2	33.9	599.3	726.0
Total forest area by classes of dimension	223.9	968.0	881.3	15.24.0	3024.1	3513.8	22355.9	32491.0
(%)	0.7	3.0	2.7	4.7	9.3	10.8	68.8	100
ALGARVE								
No. of private forest owners	5307	1121	226	118	43	14	8	6839
No. of properties	10356	7421	2207	1090	704	118	72	21968
Area of forest stands	1250.0	2469.2	1576.5	1584.6	1267.8	931.5	1185.4	10256.0
Area with bush and with forest	2359.9	2764.4	1461.3	846.3	440.0	271.4	1021.9	9131.2
Total forest area by classes of dimension	3575.9	5224.6	3037.8	2430.9	1707.8	1202.9	2207.3	19387.2
(%)	17.9	26.1	15.1	12.1	8.5	6.0	11.0	96.7

In this first assessment (2003), the non-industrial private forest represents 76.6%, and private industrial forest accounts for 7.7% of Portugal's total area of forest land. Comparing these data with the values mentioned by the ICNF (2021) shows significant differences in the aggregated values, reflecting substantial uncertainty resulting from the considerable gaps in the cadastral situation.

Table 21 data shows the remarkable dominance of private forestry property, and the structures that characterize it are quite different in the North and South of Portugal. The private forest north of the Tagus River is characterized by the predominance of tiny plots and the dominance of conifers (pine forests) and fast-growing eucalyptus trees. The south of the Tagus River dominates the ownership of large dimensions, often associated with agricultural activities, forestry, and pastoralism, where the cork and holm oak predominate.

In the northernmost regions of Portugal, the forest is mainly owned by property owners of small dimensions (less than 5 ha). Owners of medium and large estates (over 50 ha) are few.

In the southern regions (Ribatejo and Alentejo), the large property predominates (over 100 ha). Although there are many groups of small landowners, the area they own is not very important to the total forest area of these regions. Ending up in the Algarve region, the property structure presents intermediate characteristics between the set formed by the North and Centre and the set encompassing the Ribatejo and the Alentejo. The small property is predominant there, but the extensive property has a significant position.

At the origin of the significant disparity in the property's structure are historical and socioeconomic facts, in addition to the physiographic characteristics of each region. In brief, we can point out that the large property in the country's south originated in the Christian reconquest of the territory in the 12th and 13th centuries. The kings donated large tracts of land confiscated from the Moors to nobles, religious orders, convents, and secular clergy. With the triumph of liberalism in the 19th century, part of the great property passed into the hands of the nobility that supported the revolution, and the urban bourgeoisie triumphantly acquired the other part. In the North, the property has always been more divided due to relief conditions, demographic pressure, and the rural property inheritance system.

There is, however, still great uncertainty since, according to the ICNF (2021), only 46% of forest areas have a land registry. About 11.7 million rural properties are under agroforestry use, and 1,107 are Baldio units. It is estimated that there are 200,000 forest owners (6th National Forest Inventory, 2015). We can also see that this dispersion favours the significant lack of management plans the Portuguese forest has suffered for a long time. The available information states that the area of Portuguese forest under management plans is around 22%, in contrast to European figures, whose average is about 70%.

In addition to the historical reasons referred to above, we should mention the persistence of a strong atavism that has characterized the pace of rural development and the absence of an effective succession law to contain the successive division of land or promote rural reparcelling.

To document the slowness with which this critical structural problem of forest property has been addressed in Portugal, we think it helps to mention that already in the distant years of 1958, in the preparatory studies for the "II Plano de Fomento 1959-1964" [2nd Development Plan], this size constraint for viable forest management was already highlighted. For the pine forest in the central region of Portugal, the following values of the forest smallholdings were referred to: average forest stand size 0.46 ha; middle area per owner 4.14 ha. In several municipalities in the pine forest area, we found the following values:

- Oleiros (4,312 ha), with a forest area corresponding to 60% of the dominant area of properties, was between 4 and 28 ha.
- Sertã (43,988 ha) a percentage of 60% of forest properties had an area of less than 1 ha and 30% with a size between 1 and 4 ha, and 10% with an area greater than 4%.

- Vila do Rei (19,344 ha) with a percentage of the forest area of 90%, with 70% of properties with an area up to 0.5 ha, 20% with a size between 0.5 and 1.0 ha and 10% with an area greater than 1 ha.
- Condeixa a Nova (8.6676 ha), with a percentage of the forest area of 30%, had a share of 20% of properties with an area of less than 2 ha and 70% with sizes between 2 and 6 ha, and 10% with an area greater than 6 ha.
- Penamacor (62,784 ha), with percentage of the forest area of 25%, the forest properties with an area between 1-5 ha, represented 50% of the forest area.
- Soure (26,184 ha), with a percentage of 61% of forests being 58% of the forest properties with a size less than 1 ha, 10% with areas between 1-6 ha and 32% with areas higher than 5 ha.
- For Santarém, we found 11% for a total of 56,258 ha, with a percentage of 10% with areas up to 15 ha, 70% with sizes from 15 to 100 ha and 20% with areas greater than 100 ha.

For all these municipalities, some of which depend almost exclusively on forestry, it was said that there was no specific technical organization to support forestry exploitation.

Resolving the severe structural problem of small and dispersed forest properties is one of the major issues hindering the modernization of Portuguese forestry. Because of that, intervening is urgent since it affects the ability to manage the forest properly. It is a question here of deciding how to aggregate micro and small forest properties and regulate inheritance law, as has been done for many years in many European countries, to guarantee a scale compatible with solid forest management and planning standards.

The second problem, which is also somewhat interconnected, concerns the absence of a coherent forest policy and an integrated national executive structure. One cannot forget that land is the operative link between biodiversity loss and climate change and, therefore, must be the primary focus of any meaningful intervention to tackle these intertwined crises that cannot be tackled with disjoint policies addressing agriculture, forest development and conservation and rural development separately.

Due to inefficient and disjointed rural development policies and cohesion efforts, the interior territory has been progressively depopulated, negatively impacting the management and maintenance of forest areas and soil integrity. It cannot be forgotten that the continuous depopulation of the interior of Portugal and the degradation of forests are added to the fact that the Portuguese public forest (2 % of the Portuguese forest area) is the smallest area of public forest in the EU, as well as in all other Mediterranean countries. This small expression of the public forest means not only a retraction of forest technical support but also the inability of the State to encourage more responsible and productive behaviour by small forest owners. It also means withdrawing the State's presence and power over the interior territory and the ability to optimize the forest's externalities.

Recently, UNCCD[474] (2022) stated, "*Investing in large-scale forest land restoration is a powerful, cost-effective tool to combat desertification, soil erosion, loss of forest and agricultural production*". It is essential to recognize and act coherently because Portugal cannot afford to continue taking land for granted. After all, the soil is a finite resource and our most valuable natural asset.

---

[474] UNCCD (2022) - *Global Land Outlook*, 2nd ed. *Land Restoration for Recovery and Resilience*. UN, 204 pp.

Contrary to what several development support institutions always insist that it is the government's responsibility to verify whether there are training facilities for extension technicians, Portugal has neglected the creation of a forest extension body with the technical and human capacity to act in both technical assistance and social mobilization despite the examples available in Europe. Among several examples available on the development of bodies supported by the State, we mention the Forestry Council in Federal Germany, the Dutch Property Board for Small Forestry and also the Norwegian Forestry Associations, that was instrumental in the elaboration of the fundamental elements to the design of the Norwegian forest management law including the details for the elaboration of an exploitation plan for each property including the forest and financial balance. These plans included data on the owner's requirements and labour supply, the credits he has accumulated for carrying out in his woods, his taxes, his cut over the last ten years, his equipment and physical development for forestry, and his willingness to invest additional amounts.

As a mere example of the explanation for the high level of development of forestry activity in Norway and of the proactive actions taken by the government to promote an active technical culture among small forest owners, we should note that this society, only in 1954, drew up 508 individual plans to small properties from 50 to 370 hectares.

It is consensual that to solve the fragmentation problem of forest patches, it is necessary to consolidate individual properties so they can reach economically viable management units. Despite the critical role to be played by education and forestry extension, it is generally accepted that valuable results cannot be achieved without the support of adequate legislative measures on inheritance law and, even more recently, with active reparcelling measures.

The succession law regulation measures have been part of the legislation of many countries for many years to maintain viable farms. Thus, for example, in Norway, the fundamental legislation still in force (Lov angående Odel Seg Åsetesretten av 26 juni) dates from 1821. In it, the law determines that the succession "Mortis causa" belongs to the eldest son, who will retain the property upon payment of a fair price. If the latter is not interested in the property, the next brother succeeds him by right and so on. If all the children decline their right of succession, any direct member of the family can claim it up to the end of a period of 3 years by paying the price fixed in the district. In the case of sale outside the family, the law prefers buyers residing in the community. Another diploma of 22 June 1928, which strengthens the maintenance of the property and follows the line of land reparcelling of the forest property, allows a rural owner who needs additional land to balance its exploitation and who is not able to obtain it by purchasing adjacent plots may resort to a judicial process to get it, intervening in the consideration and resolution of the case the District Land Board being the final process approved by the Ministry of Agriculture.

In Finland, cooperative-type organisations in rural communities were developed to guarantee the integrity of forest areas, where no fragmentation is allowed, and even firewood consumption is paid to the cooperative bank.

In Denmark, for example, one of the measures included in the Law of October 1919 to encourage the increase in the area of forest properties determined that forest properties with less than 10 ha could not benefit from government aid. In France, the law of December 1954 represented an excellent example of progress in stabilizing forest ownership through the regulation of inheritance law. In that country, the concentration of properties was carried out at that time at a rate of 1Mha/year, and in Spain, property consolidation works were carried out at a rate of 600,000 ha/year.

There are also other examples available in the world that show the effectiveness of systems of cooperative or co-participated exploitation and management of natural resources, as seen among others in Germany, Austria, Ireland and the USA, where associations of ecologists who hold and manage nature reserves, and in which they are led to generate balance between the parks' profitability objectives and the needs of the people who live and work there, as well as the goals of protecting the environment. Finding new ways to preserve common goods and generate the public good requires some forms of cooperation, starting from the possibility of promoting the coordination of local and national decisions.

At the EU, the case of Ireland, which also grappled with the problem of smallholder forestry, offers a successful example with its "Farm Forestry Partnerships Scheme, Coillte), established in 1993 and which in 1994 managed 400,000 ha of forests employing 1,100 people directly and over 2,000 contract staff of which 95% of them are scattered throughout Ireland regions allowing them to play a significant role in rural development. Under this scheme, the landowner and Coillte enter into a partnership agreement. The landowner retains ownership of the land and makes it available for planting and management. Coillte supplies the plants, carries out the necessary preparatory work and planting, and manages the crop. This ensures that the forest will be planted and managed to the highest standards and later harvest and market the timber crop. The landowner can invest in forestry yet avoid planting and maintenance costs and, in return, receive an annual income.

In Portugal, when looking at inheritance laws, we see that agricultural units appear as an undifferentiated patrimonial asset that, in "Mortis causa", is shared without distinction between the heirs according to their market value - completely alienating their nature as a means of production and its role in the national economy. The law determines that the shares be filled with the greatest equality, forming lots integrated, as far as possible, by goods of the same kind, thus leaving the co-heirs total freedom to destroy the whole, which they divide and subdivide, equating the lots with aliquot parts of the buildings when they do not admit legal division. Regarding the total inadequacy of this law, we recall that in the report of the Corporative Chamber (1958) on the proposed law on the 2nd Development Plan (1959-64), it was already mentioned "*the unsustainable nature of the present situation and only accepted as bearable by those who are still dominated by a mentality that seems to have deviated from the paths of the world, almost incomprehensible in today's Europe, which urgently needs to be reformed.*" After so many years, we still haven't taken the necessary modernization steps to mitigate the ongoing dismemberment of forest property.

Only in 2020, through Law 111/2020 and Decree-Law 29/2020, did the government recognize that property fragmentation must be addressed. This law, however, is not explicitly addressed to the forest sector but to agriculture establishments in general. Its wording is precise as to its intention: "*The land structure in Portugal, marked by the dispersion, fragmentation and small size of the property, particularly in the north of the Tagus, presents structural deficiencies that compromise the viability and economic sustainability of the holdings, leading to the abandonment of agriculture and areas without bush and forest management. This context of retraction of traditional activities, aggravated by the ageing population, has been increasing the tendency to abandon the rural territory*".

As it is worded, it must be understood as a general instrument of territorial management and not a specific instrument to deal with forest fragmentation. The wording is precise: For this purpose (mitigate general rural fragmentation), "*it is essential to encourage landowners to invest and manage their rustic properties, namely through the improvement of the land structure, which justifies the creation of measures to support land consolidation aimed at territories classified as vulnerable*".

In this context, the Program is created "*to promote the increase in the physical size of rustic establishments and, thus, increasing the viability and economic sustainability of the farms that are installed there or will be installed there, to increase the planning and management of these same areas and, consequently, the resilience of the territories and the preservation and promotion of agroforestry activities*".

Interestingly, throughout the entirety of the law, the only reference to the forest appears in the scope of application (article 2), which establishes that, in the case of forest land consolidation, the maximum size of eligible land corresponds to the exploitation of rainfed farms. This clause clearly shows that the legislator was unable to understand that the scale requirements of a rainfed agricultural system and a forestry system are significantly different. It is doubtful whether this single reference to forest land did not appear only to justify that the credit line created for rural establishments is financed (Article 4) by funds from the Permanent Forest Fund (FFP), which ensures the financial charges of the application of this decree-law; the annual allocation for each support being fixed by order of the member of the Government responsible for the FFP, by the budget allocation available for this purpose and transferred to the Agriculture and Fisheries Financing, P.I. (IFAP).

Again, this is another example, after so many years of witnessing several unconnected institutional arrangements and legislation to deal with this severe structural problem of the Portuguese forest after the incipient experiments of forest cooperatives in the seventies.

A brief outlook on European countries shows that several actively manage 100% of their forest, such as Austria, Bulgaria, Finland, and the Czech Republic. Although there is a tendency to justify this delay in forest management in Portugal as being due to the high dominance of the forest in private ownership, the comparison with other territories (UNECE Database – United Nations Economic Commission for Europe) seems to cast doubt on a direct relationship between the type of property – public or private forest – and whether it is managed or not. Some countries with 100% forest under management have mostly private forest ownership, such as Slovenia and Finland (75% and 70%, respectively). In others, such as Turkey, Bulgaria, or the Czech Republic, forests are mostly public (99.9%, 88%, and 77%, respectively). What makes the difference is the political will and models adopted by the organization.

Looking at the current matrix of institutions (Figure 37, pp.137) and leadership responsible for defining and implementing forestry policy, one can imagine the entropy of the system and the almost inevitable stoppage of action that naturally results from the mixture and uncertainty of concepts and interpretations across the chain.

The articulation model for implementing the Forest Policy adopted shows significant compartmentalization under many different authorities, which makes compatibility and harmonization of interventions at the regional and local levels too complex and, in many cases, obscure and a propitious field for arbitrariness and even corruption. It is a model where communication is long, and the potential for entropy generation is accentuated.

These long communication chains are obstacles to speeding up processes in good time. Is it not time to ask ourselves if it is not because the present organizational model is not adjusted and because it favours a situation where there is not a true owner of the problem who takes in due time the decisions and carries them through that the forest sector suffers an unsatisfactory regression for the environment and the economy? Is it not because communication and decision-making chains are very long and because there is no problem owner that no one is ever held responsible for situations of degradation of our country's natural heritage?

Without minimizing the importance of climate change, we believe that, in this case, its evocation to justify the problems of what is happening to the sector is a lousy excuse.

In 2010, ICNF registered 150 Forest Producers' Organizations (OPF), which include associations of landowners, forest cooperatives or cooperatives with a forest section, and their federations, 77% of which are at the municipal level, in addition to 6 recognized Forest Management Entities. Since 2005, the Forest Intervention Zones* (ZIF), have significantly expanded, which currently cover 1.7 Mha and include more than 23,000 adherent owners and 84 managing entities (among associations, cooperatives, and companies). However, a concrete analysis of their operation, the technical framework that supports them, the constraints they face, and the results achieved are so far very scarce or unknown.

The current scenario in terms of territorial management shows that the ICNF is responsible for managing 62,551 ha of State land and for ensuring the co-management of more than 300,000 ha of vacant land subject to the forestry regime (this area will be outside the responsibility of the ICNF management due to the last Baldios law of 2017). 11.7 million rural properties with agroforestry use and 1,172 communal land units are registered in the real estate matrix. In addition to this challenging management situation, only 46% of forest areas are estimated to have land registration. The ICNF also estimates that more than 20% of the territory has no owner or is unknown. We can imagine that this vast void of knowledge about the effective ownership of properties and the immense gaps on the limits of many "baldios", leading to frequent claims in the courts and the freedom of political exploration of this vast field of uncertainty, provides an expansive room for manoeuvre and manipulation in the application and allocation of financial instruments aimed at territorial cohesion, or rural development, to name a few.

The continuing lack of appropriate legislation and incentives for forest owners to treat their plots properly as potentiating the generation of environmental goods and services is also worth mentioning. Forest's role in watershed protection and in arresting land degradation is particularly significant and critical in uplands and arid areas and has not been appropriately considered in legislative terms. One cannot forget watershed degradation and reduction of the dam's storage water capacity caused by heavy siltation, as can already be seen in Portugal due to increased soil erosion, affecting water availability for the population in general, for irrigated agriculture and power generation.

Intensification of agriculture in Portugal, critical to overcoming food insecurity, requires measures to protect watersheds and arrest land degradation. Since water is a key resource, the role of forests and trees in altering evapotranspiration and infiltration and thus affecting downstream water availability must be fully understood.

Although the inadequate structure of forest ownership is of great importance in the current situation of the Portuguese forestry sector, we cannot exempt from this situation the lack of adequate legislation and coordinated efforts for rehabilitation and afforestation to solve the critical problems of Portuguese forestry whose area has been decreasing at a significant rate of about 0.3% per year this century.

Despite Portugal's significant forestry potential, much of the land suitable for forestry growth is being used for other purposes or, as it is the case, left abandoned, increasing uncertainties about its future performance in the growing inability to satisfy the installed industrial capacity endangering the future of the forest industry heavily dependent on maritime pine and eucalyptus wood supply.

---

* A Forest Intervention Zone (ZIF) is a continuous and delimited territorial area, consisting mainly of forest spaces, subject to a Forest Management Plan (PGF) and which complies with the provisions of the Municipal Forest Defense Plans Against Fires, and administered by a single entity, which is called ZIF Management Entity.

In this context, the analysis of the historical series of successive National Forest Inventories unequivocally demonstrates, in the most recent inventories, the degradation of the age structure of maritime pine stands due to the reduction of the areas occupied by older strata (Fig. 39) knowing that the dimensions of the most desired woody material for the sawmill industries are concentrated in them. In the case of eucalyptus, there is a trend towards an increase in strata above 12 years, which may reflect a growing trend towards less active management practices or abandonment, as this species is mainly exploited for the wood pulp industry in short revolutions up to 12 years.

Again, this lack of full forest potential utilisation is in some ways due to land ownership structure and the high levels of mixing of species in a single small forest plot, making cost-effective management and felling complicated and expensive. The lack of proper corrective legislative initiatives favouring the consolidation of forest holdings and the depopulation and ageing of the population has its share in the present degradation situation of the national forests.

The dispersion of decision-making bodies in the context of municipalities and parish councils, without qualified technical support or financial instruments and measures to prioritize actions in the broader framework of landscape units without defined strategic objectives, is certainly not the appropriate way to solve the problems of deforestation and the recovery and sustainability of the forestry heritage, nor of guaranteeing the sustainability of the forest products industry. Nor is it the best way to reverse the interior's depopulation or invest rationally in the scarce funds available.

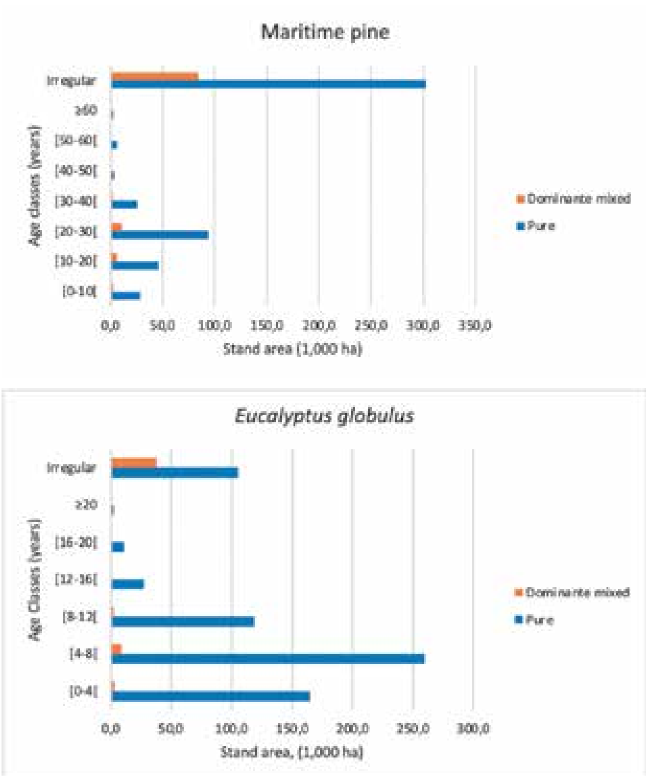


Fig. 39 – Maritime pine and Eucalyptus Forest cover area by age classes
Data source: 6th National Inventory, Final Report

From the combination of those factors we can see that contrary to what happens in other Southern European countries of the Mediterranean basin, the current situation of the decline of the Portuguese forest area is mainly due to the inefficient and disjointed forestry policy translated by the absence of significant action, maladjustment of the structure of the public services to support forestry, the dispersion of the intervening entities and their disarticulation and inability to mediate between different views on functions and objectives that should be requested from forests for each landscape unit. We are witnessing the confrontation of those who uncompromisingly defend the primary purpose of the protective function and those who emphasize the productive function. It is a false debate because there is hardly a protected forest that survives if it is not profitable, whether in direct or indirect goods, just as a productive forest that is not managed sustainably will not be sustainable.

So, the main drivers leading to the abandonment of many small forest holdings are the structure of the Portuguese forest properties dispersed and dominated by small plot owners, lack of policies and instruments attributing to small forest owners the benefits of externalities generated by the conservation of their parcels. When the market does not appropriate these values, their owners, who live on meagre incomes, do not feel encouraged to assume costs with their conservation. The very smallness of the public forest, which does not have a territorial dimension or representation and is not equipped with a proper extension structure, can hardly model conservative management behaviours.

6.2.1.4 – Economic indicators

Despite this relative disinterest in the fate of the Portuguese forest, what is irrefutable is, without a doubt, still the socioeconomic and environmental importance of the forestry sector in Portugal.

Although the global economic situation of the sector is still favourable, it faces intense pressure, as can be seen from the evolution of macroeconomic indicators. In fact, in 2020, the Gross Value Added (GVA) of forestry decreased in volume and value (-6.5 % and -8.5 %, respectively), quipping a decreasing trend since 2015, with the relative weight of forestry GVA in the national economy decreasing to 0. 4% (the lowest since 2009) (Figure 40).

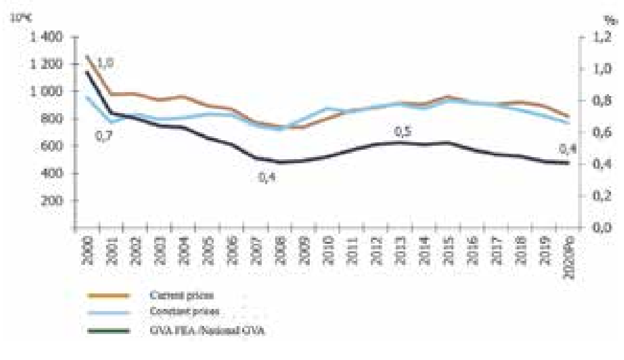


Fig. 40 - Trends of GAV in the Portuguese Forest

Source: Contas Económicas da Silvicultura [Forestry Economic Accounts], INE, 2023

Regarding forestry GVA per unit area of forest, Portugal was in 5th place, with a value (279 €/ha) well above countries where the size of woodland is significant, such as Finland (184 €/ha), Sweden (€110/ha) or Spain (€54/ha).

The decrease in production volume (-5.8%) results from the general decline in different forestry products, except wood for energy. Wood production, particularly for sawing or chipping (excluding woody biomass for energy) decreased by 9.6% and 4.6%, respectively, with cork and forestry services decreasing by 6.0%.

On the contrary, and this might have been due to the greater consumption of power for housing heating due to mandatory confinements due to COVID-19, wood for energy presented an increase in volume of 1.2% in 2020.

Concerning the nominal decrease in production (-7.2%), the highlight is the decrease in cork production weight (-6.0 %) because of variations in the same direction in volume and value (-12.6 %).

Over the last few years, the national forest production structure has registered changes that result not only from the greater incidence of fires but also from changes in land use and insufficient sustainable management of forest resources. This is how cork, which in the period 2000-2004 was the most relevant product, lost importance to wood for chipping, which began to occupy the most prominent place (39.5%) in 2020 (Fig. 41).

Fig. 41 – Produção de madeira, cortiça e outros bens
Source: Forestry Economic Accounts, INE, 2023

The negative evolution of production in absolute terms (-7.2%) resulted from decreases in most goods, with particular emphasis on sawn wood (-6.9%), cork (-12.6%) and services forestry (-6.0%) and forestry works (-6.4%). Regarding 2018, we sign that there were notable increases in the volume supply of most forestry products in that year, reflecting the extensive collection of salvage resulting from the large forest fires of 2017. As a result of this abnormal volume of wood offered in 2018, the cuts and Maritime pine timber removals and forestry services declined in 2019. Afforestation and afforestation have seen a continuous decrease since 2015.

Wood for sawing, mainly from maritime pine, continues to be produced in insufficient quantity to meet the industry's needs due to the difficulty in reconstituting burnt stands and stands already cut down, along with the abandonment of small plots of wood-pine trees. The scarcity of this raw material has been alleviated by resorting to extraordinary cuts on burned wood, a situation that did not occur in 2020. In that year, the wood production for sawing decreased in volume by -9.6%. The pressure of demand mitigated the decrease in value, which stood at -6.9%.

Although less markedly than sawn wood, wood chips also decreased in volume (4.6%). However, its price suffered a less pronounced reduction of -0.8%, accentuating the decrease in value in 2020 of around -5.4%. This type of wood, primarily eucalyptus, is mainly used by the paper pulp industry and the manufacture of chipboard panels. The disproportion between the availability of national wood and the installed capacity of the pulp industry leads to an already very significant import with all the consequences that this entails for the national trade balance.

Concerning cork, data shows that for the second consecutive year, cork production decreased in nominal terms by 12.6%, resulting in a reduced volume of 6.0% and a price of -7.0%. The price reduction is related to the decline in cork quality for stoppers. The climate of market uncertainty due to COVID-19 must also have contributed its share of the blame.

Public disinvestment from forestry producers in Portugal does not look to be promising for the sector's economy. It reveals that it has not been a priority concerning public investment. The sector's accounts show that after two consecutive years of increases, total aid paid to forestry activity (subsidies to the product, other contributions to production and capital transfers) decreased by 13.9 % in 2019 and 4.9 % from 2019 to 2020.

The amounts classified under donations, which include the maintenance premium and the premium for loss of income, were significantly reduced by 19.4 % (Fig. 42).

This reduction resulted from a 24.6% decrease in subsidies (including maintenance premiums and premiums for loss of income) and increased capital transfers (+10.7%).

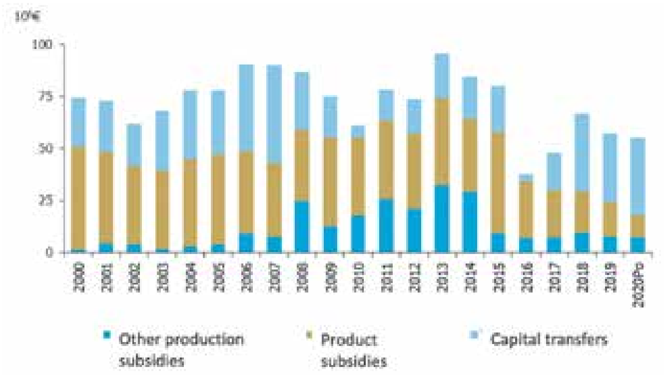


Fig 42 - Total aid paid to forest production

Source: Forestry economic accounts, INE, 2023

Unsurprisingly, the Net Business Product (NBP) from forestry and forest exploitation in 2020 decreased by -13.5% for the second consecutive year, reaching the lowest value in the last ten years. Mainly contributing to this evolution of the NBP of forestry was the negative nominal variation in the GVA of forestry and forestry exploitation (-8.5%).

Concerning Gross Fixed Capital Formation (GFCF), economic statistical data shows that as in the previous year, in 2020, it decreased in volume (-4.5%) and value (-3.9%) due to the decrease of afforestation and reforestation component (from cork oak, stone pine and eucalyptus trees), which evolved negatively (-12.0% and -11.6% in volume and value, respectively). GFCF in non-forest products (equipment, construction, etc.) also decreased both in volume (+1.3%) and in value (+2.5%).

The trade balance (for the five years 2017-2021) presented includes materials of forest origin (raw materials) and industrial products of forest origin (processed products).

The results for 2021, still preliminary, show that the trade balance was in surplus, having increased after a decrease in 2020, going from 2.4 thousand M€ to 2.7 thousand M€ mainly due to industrial products of forestry origin, since Portugal is deficient in materials of forestry origin.

Regarding international trade during the pandemic (COVID-19) period, exports and imports of materials and industrial products of forestry origin in 2020 decreased by 10.0% and 12.1%, respectively. That year, total exports of goods and services decreased by 10.3%, with exports of forest products maintaining their relative weight of 8.6% in total exports of goods. In 2021, exports of industrial materials and products of forestry origin increased by 20.1%, increasing the relative weight of these products in the total national exports to 8.8%.

Imports of materials of forest origin (raw wood, natural cork, and other forest materials) are much higher than exports. In 2021, accentuating the weaknesses of our productive sector, the deficit balance worsened substantially, reaching 330.4 M€.

Cork-based products have the most significant commercial surplus (997.2 M€). Paper and cardboard come in second place with 799.5 M€. Pulp for paper, paper for recycling, and wooden furniture ranked third and fourth, respectively.

Relative positions of main forest products are set forth in Fig. 43.

As a whole (2021), forestry activities, forestry-based industry and commerce constitute a value chain with a structuring weight in the entire Portuguese economy, mobilizing around 24 thousand companies (2% of the national total) - 8 thousand in forestry, about 10 thousand in industry and close to 6 thousand in forest-based trade activities.

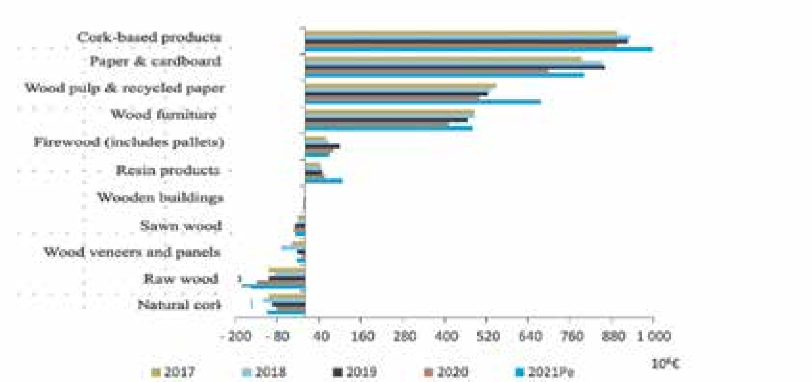


Fig. 43 - Trade balance of the main products of forest origin

Although there are insufficient statistics to draw a complete picture of the forest economy in all its components, we know that forest-based industries - wood, cork, furniture and paper pulp, cardboard, paper, and biomass - generated a turnover in 2021 of almost 10.7 billion euros.

Economic data[475] for 2021 indicate that together, forest-based industries and forestry companies generated a turnover of more than 11.69 billion euros, contributing, respectively, to 4.98% and 0.47% of the national Gross Domestic Product (GDP), that is, the value of all final goods and services produced in Portugal that year.

Together, forestry-based companies in Portugal were responsible in 2021 for more than 2.9 billion euros in GVA. Even with some variations since 2015, in which the sector is responsible for around 2.2 billion euros of GVA, industrial activity has been responsible for about 90% of this total (and forestry for the remaining 10%). This also means that the GVA of the forestry sector was responsible for 1.6% of the total national GVA (INE[476], 2021).

Economic values undoubtedly show that Forest-based industries are a robust component of the sector and the national manufacturing industry. Despite the abandonment to which the wood production sector has been subjected, forest-based industries contributed 10.4% of the turnover of the entire national manufacturing industry in 2021, which stood at 102.856 billion euros.

Regarding investment, it is worth highlighting that in 2021, forestry-based industries totalled 584 million euros in Gross Fixed Capital Formation (GFCF), corresponding to investment in fixed assets used for more than a year in producing goods and services. This value represented almost 13% of the amount in GFCF of the total national industry. However, it should be noted that the investment values of the forest-based industry have shown significant annual variations in recent years, with a minimum of 323.7 million euros in 2016 and a maximum of 731.7 million euros in 2018.

The economic importance of forest-based industries and their dependence on a robust dynamic and sustainable forest production sector makes it easy to see that land use and sustainable forest management issues are vital concerns for producers and consumers.

Regarding land use, available data shows a significantly abandoned area and increasing timber imports to meet installed industrial capacity. It is, therefore, questionable why the forest area and public forest financial aid are decreasing. In addition to the financial constraints arising from the structure of the property and the weak mechanisms for its reform to allow for the scale gains necessary for adequate management, there is one that stems from the fact that forestry, from the point of view of land use capability, is classified as a non-agricultural activity, which means that only land deemed unusable for agricultural use can be used for forestry. Historically, the national agricultural land reserve (RAN) was delimited by the use of classes A, B and C (representing around 10-15% of available land), leaving the lower grades (D and E) for forestry use. In 1989, those responsible for managing the RAN, and because of the need for higher land productivity, started to cover only classes A and B (6-7% of available land). However, when the local territorial planning authority was decentralized and passed to the municipalities, they created their own RAN list, which expanded the land eligible for agriculture (up to 16-17%). Despite this increase in the area for agricultural activity, Table 17 shows a continuous decrease in cultivated agriculture. Despite the rise in the areas susceptible to afforestation, the same negative trend is also reflected in the forestry sector.

This picture portrays one of the many obstacles to developing the Portuguese forest and the lack of tunning in designing and maintaining an integrated policy for a sector with substantial

[475] Economia da floresta: Quanto vale? Florestas.pt, 25 de maio, 2023 [https://florestas.pt/valorizar/economia_da_floresta_valor_gerado/#:~:text=Com%20o%20seu%20volume%20de,situou%20nos%20102%2C856%20mil%20milhões]

[476] INE (2021) – Volume de negócios das empresas por atividade económica e escalão de pessoal ao serviço anual.

implications for land use planning and better use of the territory and its natural resources. The Forest sector in Portugal is immersed in a striking paradox. It is said that they are treasured and represent a critical green infrastructure that can help address the pressing challenges that emerge from global climate change. However, our society seems to have lost the capacity to understand those values, insert them into the economic flows, and develop a balanced approach to sustainable management of their forests.

Furthermore, it is necessary not to forget the organizational entropy that the forestry sector suffers, with the diversified dispersion of competencies by countless entities that run over and cancel each other out. In operational terms, it means that the forest policy does not have a problem owner; it does not have a direct national, regional and local design with clearly defined and financed objectives and temporal targets that must be achieved (Porter[477], 1994). Compounding this problem, the lack of a comprehensive view and a single forest policy problem owner made policymakers victims of short-term fluctuations in public opinion, as already referred to by Porter (1994). The issue of increasing the amount of forest at the putative expense of agriculture and the increasing eucalyptus in the forest mix is a cause for great public concern since it heralds a significant change in traditional farm life. Information and discussions about the future of the Portuguese forest are polarized by fires and eucalyptus, forgetting the central question: how will we recover, maintain and increase the forest area by afforesting uncultivated areas that have a forestry vocation or have been destroyed by fires and guarantee the supply of the national industry and an accrue role in climate change mitigation?

In summary, we think it fair to say that it is urgent to consider the planning conditions necessary for success:

• Government determination.

• Sound political and social case for the selection of a permanent forest estate

• Long-term security forest estate, once chosen

• Adequate information is needed to select the management model, plan and control the forestry assets.

• A flexible predictive system for planning and control and resources needed for its implementation.

6.2.2 – The agriculture sector.

In terms of agriculture activity last survey[478] (2019) shows the registry of 290 thousand farms, 15 thousand less than in 2009, which corresponds to a reduction of 4.9%. On the other hand, the Utilized Agriculture Area (UAA) increased by 8.1% compared to 2009, occupying about 3.9 million hectares (≈ 43% of the territorial area). The average size of farms increased by 14.1%, from 12.0 hectares in 2009 to 13.7 hectares of UAA per farm, which reflects a smaller increase in size than in previous decades.

Globally, agricultural work declined by 14.4%, reflecting the reduction of family work due to several factors that promoted improved work efficiency, including the resizing and

[477] Porter, M. (1994) – Construir as Vantagens Competitivas de Portugal. Fórum para a Competitividade. INETI, 267 pp.

[478] Recenseamento Agrícola – Análise dos principais resultados – 2019. INE, 2021. 166 pp.

entrepreneurship of farms. In contrast to the decrease in family work, there was an increase in salaried workers (Fig. 44).

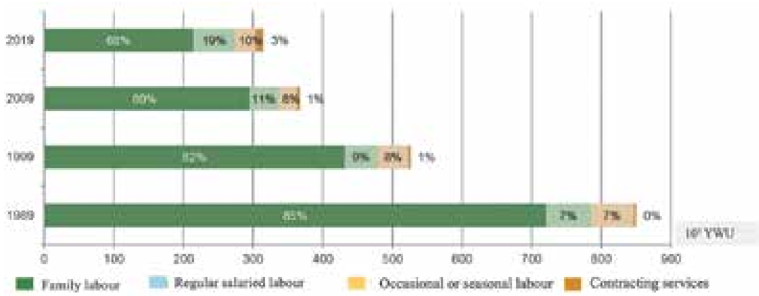


Fig. 44 - Composition of Portuguese agricultural labour in Year Work Units (YWU) (1989-2019)

Concerning the agricultural sector, workforce data shows that, as a whole, since 2009, the trends have been as the following (Table 22).

In summary it shows:

- A global decrease of 14%, reflecting familiar work force reduction. On the other hand, the hiring of salaried workers increased.
- The increase in agricultural professional training, partly due to the obligation to attend formation courses on plant protection products. This led to the extraordinary rise in the number of producers who attended agricultural professional training courses (+322.7% than in 2009). However, most producers still have exclusively practical agricultural training (53.0%), with emphasis on the Algarve, where the number of producers without any agricultural training represents 70.4%.
- The decrease in working time in the farm's agricultural activities, verifying that only 13.1% of the producers work full time (225 days or 1800 hours) on their farm (-8 %. than in 2009). Producers in the Azores and Entre Douro e Minho are the ones who work the longest on the farm, while in Madeira, due to the small size of farms, they spend less time on agricultural work.
- The decrease in the family farm population, made up of the producer and his household members, went from 793 thousand people in 2009 to 666 thousand (-16.1%), corresponding to 6.5% of the population resident in Portugal. It should be noted that in 1989 the family farm population totaled practically 2 million people, about 1/5 of the resident population.
- The maintenance of pluri-activity and diversity of income sources is evidenced by 43.2% of households declaring income from wages, and 7.5% report developing other non-farm business activities. On the other hand, only 5.2% of the producers live exclusively on the income from their activity on the farm (-1 % than in 2009). Despite being common to all regions, Azorean agricultural producers depend more on farming income.

In Alentejo, salaried labour represents 56.1% of the total agricultural labour force (46.6% in 2009) due to greater entrepreneurialization and the average size of farms. For the same reasons, in "Ribatejo e Oeste", the volume of salaried labour is higher than that of the family, and the regional importance of specific production guidelines that are very demanding on the workforce. In contrast, in "Beira Litoral" and "Entre Douro e Minho", where the predominance of small farms is very significant, the use of hiring labour is considerably lower, respectively 16.4% and 19.3%, reaching the lowest representation in Madeira (13.9%). Hiring occasional or seasonal agricultural labour carried out directly by the producer is of greater importance in the Alentejo and Algarve regions, where farming services are more representative.

Table 22 – Year Work Unit according to type of labour by Agrarian Region

Agrarian regions	Total labour in agriculture			Family labour			
				Producer		Producer relatives	
	YWU	Distribution (%)	Variation 2009-2019 (%)	YWU	Importance (%)	YWU	Importance (%)
Portugal	314,509	100.0	-14.4	120,213	38.2	93,771	29.8
Continent	293,236	93.2	-14.1	109,949	37.5	87,042	29.7
EDM	56,658	18.0	-28.1	23,292	41.1	21,813	38.5
TM	62,774	20.0	-9.5	26,734	42.6	21,501	34.3
BL	47,053	15.0	-28.2	20,760	44.1	18,168	38.6
BI	27,098	8.6	19.2	12,189	45.0	9,524	35.1
RO	41,752	13.3	-11.7	12,153	29.1	7,878	18.9
ALE	44,182	14.0	23.9	10,487	23.7	5,360	12.1
ALG	13,720	4.4	20.0	4,335	31.6	2,799	20.4
Azores	10,594	3.4	-8.1	5,147	48.6	2,706	25.5
Madeira	10,678	3.4	-25.6	5,117	47.9	4,024	37.7

	Labour outside family producer								
	Hired directly by the producer							Contracting services	
	Total			Regular salaried labour		Occasional or seasonal labour			
	YWU	(%)	Variation 2009-2019 (%)	YWU	Importance (%)	YWU	(%)	YWU	Importance (%)
Portugal	90,158	28.7	30.7	59,808	19.0	30,350	9.7	10,367	3.3
Continent	86,100	29.4	32.5	57,110	19.5	28,990	9.9	10,146	3.5
EDM	10,917	19.3	35.5	6,975	12.3	3,942	7.0	637	1.1
TM	12,783	20.4	7.8	5,539	8.8	7,244	11.5	1,756	2.8
BL	7,700	16.4	21.3	5,493	11.7	2,206	4.7	425	0.9
BI	4,991	18.4	27.5.	3,067	11.3	1,924	7.1	396	1.5
RO	20,220	48.4	27.7	14,447	34.6	5,773	13.8	1,502	3.6
ALE	24,777	56.1	49.0	17,833	40.4	6,945	15.7	3,558	9.1
ALG	4,713	34.4	103.2	3,755	27.4	958	7.0	1,873	13.7
Azores	2,576	24.3	15.8	1,982	18.7	594	5.6	165	1.6
Madeira	1,482	13.9	-17.9	716	6.7	766	7.2	56	0.5

Data source: Recenseamento Agrícola 2019, INE, 2021, 166 pp

A high level of ageing marks the Portuguese agricultural workforce, as seen by the higher representation of the age group over 65 years old and by relatively low levels of education, especially in the older group (Table 23).

Table 23 - Average age and education level of agricultural producers and leaders of agricultural societies

Category	Total		Ages Classes			
	Individual numbers	Variation (2009-2019)	>25	[25;45[	[45;65[	>65
Singular producers	274,246	-7.8	811	27,409	101,962	144,066
Societies	14,604	115.5	1000	4,676	7,376	2,458

	Level of training						
	None	1st cycle 4 years	2nd cycle 9 years	2yr education 2 years	Non-agricultural Higher Educat.	Agricultural Higher Educat.	Complete agricultural training
Singular producer	29,036	127,053	65,314	27,03	21,988	3,654	4,899
Leadres of Agri. Societies	149	1,368	3,071	2,994	4,236	2,786	3,279

Data source: Recenseamento Agrícola [Agricultural census] 2019, INE, 2021, 166 pp

The worsening ageing of Portuguese agricultural producers translates into a 2-year increase in the average age of producers compared to 2009. This ageing is transversal to all regions, although it is more relevant in Beira Litoral and Algarve, regions where the average age of the producer is 67 and 68, respectively. In the Azores, the average age of producers is the lowest, 55 years old.

The singular agricultural producers are primarily men (67.1%, on average 64 years old, 46.3% have only completed the first level of education, and 1.8% have completed agricultural training).

In the evolution of productivity that has been observed in Portuguese agriculture, in addition to the factors revealed by the change in the number and size of family farms, the changes that have been observed in the age of farmers and their levels of education that is a pre-condition to enhance the introduction of new technologies and innovation.

It is an unprecedented evolution compared to previous surveys generally noted in all NUT II, except for the Autonomous Region of Madeira. On the other hand, the area with agricultural potential but not being used has kept its downward pace since 1999, reducing by more than 36 thousand hectares, representing 1.8% of the total surface (2.7% in 2009 and 3.9% in 1999).

Of the nearly 4 million hectares of UAA, more than half is covered with permanent pastures (51.7%, compared to 48.7% in 2009), followed by arable land with 26.2% (32.2% in 2009) and permanent crops (21.7% compared to 18.8% in 2009).

Compared to 2009, there was a decrease in the area of arable land (-11.6%), a substantial increase in permanent crops (+24.6%) and a similar increase in permanent pastures on deforested land and under oak forests (+ 14.9%). This evolution reinforces the trend observed in Portuguese agriculture towards a decrease in arable land (which has already lost 136 thousand hectares since 2009) and an increase in permanent pastures (+265.99 thousand hectares compared to 2009). This trend from the previous decade seems to be reversing due to the increase in its area, compared to 2009, with an additional 169.9 thousand hectares.

The decrease in arable land, which has occurred since 1989, was essentially due to the reduction of the cultivated areas of cereals for grain (-32.2% compared to 2009) and potatoes (-28.6%), crops that were not very competitive given the opening of international markets. On the other hand, there was a significant increase in the area of legumes for grain (+41.2%), which is believed to be due to a specific diversification of crops and cultural practices eligible under the greening measures. The 8.3% increase in the area of vegetables reflects the production response to increased consumer perception of the importance of vegetables. The flower and ornamental sector also registered an expansion of 17.6% in installed areas.

The area of temporary meadows and forage crops grew by 12.0%, occupying the majority of temporary crops (49.8%) (Fig. 45).

The abandonment of agricultural activity by a significant number of farmers, verified between 1989 and 2009, registered a marked slowdown in the last decade, even tending towards some stabilization, evidenced by the small decrease in the number of agricultural holdings but mainly by the unprecedented increase in UAA.

The abandonment of agricultural activity since 2009 occurred mainly among small producers, with the number of farms with more than 20 hectares increasing (+16.1%). The increase in the average size of farms did not result from a concentration of land in large production units, which did not register significant changes either in number or in the respective UAA, mainly due to the effective resizing of medium-sized farms. However, the approximately 1,100 farms with more than 500 hectares continue to manage more than 1/4 of the UAA, including some common lands, mostly pastures, managed by co-owners or committees entitled to their use.

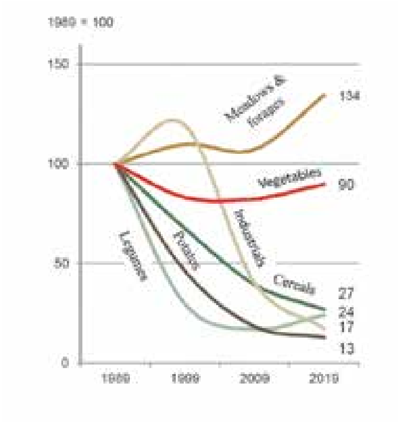


Fig. 45 - Temporary crops (1989 – 2019)
Source: INE, 2021

The decrease in the number of farms occurred mainly in “Ribatejo and Oeste” (-11.9%) and on the coast, namely in “Beira Litoral” (-15.2%) and Entre Douro e Minho (-9.1%), regions with a high number of small farms. In Alentejo, only 2.2% of farms ceased activity in the last ten years, whereas in “Trás-os-Montes” and Algarve, there was an increase in the number of farms. On the other hand, in Madeira, the abandonment of agricultural activity was negligible, confirmed by the slight decrease in the number of farms. On the other hand, UAA registered a general increase except for the Autonomous Regions. The average size of farms thus increased in most regions, although there were decreases in "Trás-os-Montes" and the Autonomous Region of Madeira (Table 24).

Table 24- Number of farms, UAA and average size, by Agrarian Region (1999-2019) (cont.)

Agrarian region	Farms		UAA		Average UAA/farm	Variation 1999-2019		
	Nos	%	ha	%	ha/farm	Nº of farms (%)	SAU (%)	ha/farm (%)
Portugal	290,229	100.0	3,963,945	100.0	13.7	-30.2	2.6	47.1
Continent	266,039	91.7	3,938,708	96.8	14.4	-30.4	2.7	47.6
EDM	44,560	15.4	212,639	5.4	4.8	-34.0	-1.4	49.5
TM	65,211	22.5	450,701	11.4	6.9	-6.8	-1.6	5.7
BL	44,245	15.2	129,848	3.3	2.9	-44.6	-23.5	37.9
BI	33,617	11.6	391,754	9.9	11,7	-30.4	-6.5	34.4
RO	34,486	11.9	409,095	10.3	11.9	-44.0	-8.7	63.2
ALE	31,131	11.7	2,144,066	55.9	68.9	-13.3	11.4	28.5
ALG	12,789	28.7	100,605	47.3	7.9	-32.6	-1.3	46.4
Azores	10,656	3.7	120,632	3.0	11.3	-44.7	-0.6	79.9
Madeira	13,543	4.7	4,604	0.1137	0.3	-6.8	-18.4	-12.5

EDM=Entre-Douro e Minho; TM=Trás-Montes; BL=Beira Litoral; BI=Beira Interior; RO=Ribatejo e Oeste; ALE=Alentejo; ALG=Algarve

Data source: INE, 2021

Data set forth in Table 24 shows that the average size of farms depicted significant regional variability. In Alentejo, the average was exceeding 68 hectares of UAA, about five times higher than the national average. In contrast, in "Beira Litoral," farms had an average of fewer than 3 hectares of UAA, reaching the minimum value of 0.3 hectares in Madeira.

Concerning the legal nature of the producer, the last survey showed that most agricultural holdings continue to be managed by individual producers (94.5%). However, there is a very significant increase in the number of companies: between 1999 and 2019, the representativeness of this legal nature increased from 1.3% to 5.0%, with the rise in the last decade being particularly noticeable (+115.5%) (Table 25).

The national Total Standard Production Value (TSPV) exceeded 6.7 billion euros in 2019 (+45.7%) than in 2009, with the Alentejo contributing 27.6% and "Ribatejo e Oeste" 22.9%. The average Economic Dimension (ED) of farms was 23.3 thousand euros of TSPV in 2019, corresponding to an increase of 8.1 thousand euros compared to 2009 (+53.2%).

Table 25 - Legal nature of the producers, by UAA classes (variation 1999-2019)

UAA classes	2019						Variation 1999-2019		
	Singular producer		Societies		Other forms		Singular producer	Society	Other forms
	Nº	%	Nº	%	Nº	%	%		
TOTAL	274,248	94,5	14,604	5.0	1,377	0.5	-33.0	165.4	18.8
A/UAA	3,329	82.4	694	17.2	15	0.4	14.1	60.6	87.5
< 1	54,561	98.4	785	1.4	129	0.2	-49-3	36.8	-15.1
[1 a 5 [	150,524	98.1	2,655	1.7	307	0.2	-29.9	163.7	5.8
[5 a 20[	47,724	92.7	3,519	6.8	225	0.4	-25.2	205.7	0.4
[20 a 50]	10,632	80.9	2,329	17.7	185	1.4	-13.2	223.5	49.2
[50 a 100]	3,946	71.2	1,458	26.3	142	2.6	9.2	246.3	56.0
≥ 100	3,532	50.0	3,164	44.8	374	5.3	-18.8	164.1	60.5

Source: Recenseamento Agrícola – Análise dos principais resultados-2019. INE, 2021. 168 pp.

The large production units (over 100 thousand euros of TSPV), although representing only 4.0 % of farms (2.9 % in 2009), generated 64.8% of TSPV (55.0 % in 2009. On the other hand, 71.9 % of farms are very small (less than 8 thousand TSPV), contributing to only 9.3% of the national TSPV. Regionally, there is significant variability in the economic size of farms, partly reflected in the depopulation of the territory, poverty and the ability to modernize family farming. Farms in Alentejo generate, on average, 59.9 thousand euros of TSPV, which represents 2.6 times more than the national average and 6.7 times more than the value generated by farms in Trás-os-Montes.

According to the Technical-Economic Guidance, the analysis of Portuguese agriculture points to strengthening its specialization. In fact, 3/4 of the farms are specialized (over 2/3 of the TSPV comes from just one activity) and represent 88.4% of the TSPV, with the specialized farms increasing by 7.0% and the respective TSPV rising by 49.9 % since 2009.

Specialization in permanent crops registered the highest growth in the number of farms, mainly due to farms specializing in nuts and sub-tropical fruits, which increased by 96.7% and 100.2 %, respectively. Although there are large economic farms with mixed or combined technical and financial orientations, these farms have an average economic size lower than most specialized farms, the only exceptions being the specializations in vines and olive groves.

On the other hand, farms with undifferentiated or combined orientations decreased by 30.6% and represented only 11.6% of the national TSPV.

In global terms, there was a decrease of 177.0 thousand hectares (a reduction of about 567 thousand hectares in the census), representing a decrease of 13.7% in the area occupied by arable land. The Alentejo was the region that lost the most arable land (-103.7 thousand hectares), essentially cereals for grain and fallow fields, reinforcing in structural terms the relative importance of forage crops and temporary meadows that already occupy more than half of the land arable land in the Alentejo. It is also worth mentioning the increase of 4.4 thousand hectares in the area with pulses and the sharp drop in the area with industrial crops (namely sunflower), which decreased by around 15 thousand hectares.

Entre-Douro e Minho's area with arable land decreased by around 37.9 thousand hectares compared to 2009, although the fallow and the horticultural areas have increased. Even so, the relative importance of crops remained, with areas with forage crops and cereals for grain continuing to represent more than 85% of the regional total of arable land.

In the Central region, 36.2 thousand hectares of arable land were recorded, resulting from decreases in the area of forage crops and cereals for grain. Like Entre-Douro e Minho, fallow and horticultural areas increased in Beira Litoral, while in Beira Interior, the area with dried pulses increased by 916 hectares (due exclusively to beans).

The increases in arable land recorded in Ribatejo e Oeste and Azores were mainly due to land uses related to animal feed: temporary grasslands and forage crops. In Ribatejo e Oeste, a note should be made of the increase in the area with vegetables (1,400 hectares) and other temporary crops (essentially sweet potatoes). In the Azores, it appears that the arable land is almost entirely occupied with forage crops and temporary meadows, as opposed to the Autonomous Region of Madeira, which presents the most equitable diversification of the use of arable land in the national territory.

The TSPV of farms specialising in arable crops is around €602.0 million (8.9% of the national agricultural TSPV), with Ribatejo e Oeste contributing 43.9% of the total, followed by Alentejo with approximately 25%. These farms have an average of 18.4 thousand euros of TSPV, evidencing a significant regional heterogeneity that varies between 5.2 thousand euros in Trás-os-Montes and 76.2 thousand euros in the Algarve (practically four times the national average).

Only 3.2% of farms specializing in arable crops generate TSPV of more than 100 thousand euros. These farms are mainly located in Ribatejo e Oeste (53.1%), followed by Alentejo with 29.4% of the total.

Regionally, the relative weight of these farms once again favours Ribatejo e Oeste (11.1% of the regional total), followed by the Algarve and Alentejo with 8.1% and 7.0%, respectively, of local farms with this specialization.

An emerging facet in Portuguese agriculture since 2009 is the significant increase in the area with permanent crops, which amounts to 860.7 thousand hectares. This growth occurred for most crops, with particular emphasis on the substantial increase in the production of small berries, whose area exceeded 6.1 thousand hectares (+2,793% compared to 2009). The installation of subtropical fruit orchards was also very significant, whose surface more than doubled (+153%), particularly in kiwi orchards (+126%) and avocado trees (which already occupy an area of over 2.1 thousand hectares, mainly in the Algarve). This increase in area implied a significant increase in irrigation needs in a region where aridity indicators are already being felt. The severe drought of the last two years, mainly in Alentejo and Algarve, and the reduction imposed by the authorities in the distribution and collection of groundwater in February 2024 clearly show the recklessness in the use of crops that are pretty demanding in terms of water consumption and the lack of timely adoption of prudential measures.

Investment in fruit growing was not limited to these emerging crops, having been extended to citrus fruit (+15.8%) and fresh fruit from temperate climates, whose areas increased by 14.1%, with emphasis on apple orchards (+ 14.8%), pear trees (+5.4%) and cherry trees (+19.9%).

The production of dried fruits was another strong focus in the last decade, which practically led to the doubling of areas (+98.6%). One must also mention the installation of modern and intensive almond groves in the Alentejo and Beira Interior at the expense of reducing not only arable crops but also "cork oak forests", which significantly contributed to the doubling of the area compared to 2009.

For this evolution, the incentive given by the PDR 2020 to fruit growing will not be unconnected, as it is one of the most relevant sectors in investment support measures.

The olive groves and vineyard area represent 64.0% (74.4% in 2009) of the total surface with permanent crops. The olive groves area increased by around 41 thousand hectares, of which 4/5 are in Alentejo, which concentrates most of the national olive groves (52.4%).

The vineyard area was reduced by 4.6 thousand hectares, but there were increases in cover in Entre-Douro e Minho (+1.5 thousand hectares) and Alentejo (+5.3 thousand hectares). It should be noted that these Mediterranean crops continue to be a very present reality in national farms: 59.0% of farms with permanent crops have olive groves, and 51.9% have vineyards.

Despite the 24.6% increase in the area of permanent crops, compared to 2009, the number of farms was reduced by 9.3%, totalling now 219.9 thousand. This resizing, which increased the average size of agricultural holdings with permanent crops, was extended to practically all regions except the Autonomous Region of Madeira, which showed a diametrically opposite variation (increase in the number of holdings and reduction in area).

About fresh fruit orchards, data from the last census show that their surface grew by 14.1%, accompanied by an increase, albeit on a smaller scale, in the number of agricultural holdings (+8.0%). In summary, fresh fruit orchards are spread over 44.8 thousand farms (41.5 thousand farms in 2009), presenting an average of 1.0 hectares, 5.6% higher than in 2009. Ribatejo, West and Alentejo have higher average dimensions, double and triple, respectively than the national average. It should be noted that a reduction in the average size of fresh fruit area happens in regions with smaller farms (Entre-Douro and Minho, Beira Litoral, Beira Litoral, Algarve, and the Autonomous Region of Madeira).

The growth dynamics identified above did not change the relative weight of the main crops. Ribatejo and West remains the central fresh fruit-producing region, although it has gradually lost importance. In 1999, this region represented 47% of the total fresh fruit area, but its contribution in 2019 was around 37%. On the other hand, Trás-os-Montes and Beira Interior reinforced their positions as the central producing regions: Trás-os-Montes for apple (43% of the total, compared to 38% in 2009) and Beira Interior for peach and cherry, respectively, with 48% and 47% of the national area.

The TSPV of farms specialising in fresh fruit is around 282.5 million euros (4.2% of the national agricultural TSPV), reflecting an increase of 25.8% compared to 2009. “Ribatejo and West” contributed 42.9 % of the total, followed by “Beira Interior” with around 22%. These farms presented an average of 35.6 thousand euros of TSPV, evidencing a significant regional heterogeneity that varies between 4.3 thousand euros in the Autonomous Region of Madeira and 174.2 thousand euros in Alentejo (practically five times the national average). Less than 8% of farms specialising in fresh fruit generate a TSPV of 100 thousand euros.

These farms are mainly located in Ribatejo and West (44.1%), followed by “Beira Interior”, with 26.3% of the total. Regionally, the relative weight of these farms’ highlights Alentejo (24.5% of Alentejo farms with this specialisation), followed by “Ribatejo and West” (10.0% of regional farms with this specialisation), “Beira Interior” and Algarve with 8.8% and 8.6% respectively.

Farms specializing in citrus represent 12.3% of the universe of production units in which this culture is present. The TSPV of agricultural holdings specializing in citrus is around 106.2 million euros (1.59% of the national agricultural TSPV), with the Algarve contributing the overwhelming majority of the total (89.5%). These exploration farms have an average of 34.4 thousand euros of TSPV, almost triple the amount calculated in 2009. Regionally, it appears that practically 1/4 of agricultural farms in the Algarve specializing in citrus are of sizeable economic size, generating more than 100 thousand euros of TSPV.

Permanent pastures occupy 2.1 million hectares and are present in almost 1/3 of national agricultural holdings. The permanent meadows and pasture fields are predominantly exploited on clean land (55.1%, compared with 48.9% in 2009). Only 2.8% of these pastures are without economic use but eligible under the Base Payment scheme.

Alentejo remains the region with the most extensive permanent pastures (64.1% of the national total). In this region, the areas under cover of woods and forests (essentially cork oak and holm oak forests) have a very considerable relative weight (52.6%); however, compared to 2009, their representativeness has fallen by 8%, having been replaced, mainly by grazing on uncultivated soil.

Table 26 - Average size of livestock per farm (2019)

Region	Number of farms		Livestock	Ratio heads/farm	Variation (1999-2019) (%)	
	Farms (Nº)	%	Heads (Nº)		Nº of farms	Nº of heads/farm
Cattle						
Continent	28 531	79.0	1 294 891	45.4	-54.4	124.7
Azores	6 873	19.0	282 820	41.1	-21.3	94.5
Madeira	700	1.9	3 851	5.5	-49.7	32.6
Pigs						
Continent	25 278	89.1	2 160 819	85.5	-63.2	106.3
Azores	1 616	5.7	49 230	30.5	-55.2	52.6
Madeira	1 470	5.2	3 693	2.5	-43.2	23.4
Sheep						
Continent	41 149	96.4	2 171 753	52.8	-27.6	3.6
Azores	610	1.4	5 680	9.3	-24.5	3.0
Madeira	908	2.1	4 583	5.0	-4.6	-31.8
Goats						
Continent	20 272	88.6	359 461	17.7	-42.0	29.6
Azores	1 057	4.6	7 696	7.3	-43.2	55.8
Madeira	1 551	6.8	5 184	3.3	-19.2	-4.5
Poultry						
Continent	93 456	93.0	53 400 978	571.4	-39.4	34.3
Azores	2 564	2.6	501 736	195.7	-50.3	43.5
Madeira	4 474	4.5	600 466	134.2	24.4	18.6

Data source: Recenseamento Agrícola – Análise dos principais resultados-2019. INE, 2021

Permanent sown and improved spontaneous pastures increased by about 132 thousand hectares compared to 2009, representing 28.4% of the total permanent pastures (25.2% in 2009).

However, in Trás-os-Montes, Ribatejo and Oeste, and the Azores, the area of improved permanent pastures has decreased, although, in the latter region, improved pastures represent 90.8% of the archipelago's permanent pastures.

This positive evolution had a structural impact, with the relative importance of poor permanent pastures declining by 5%, representing 68.8% of the total range.

Cattle, pigs, sheep, and goats are the main livestock species in Portugal, significantly affecting GHG emissions. Considering the number of heads in livestock units (LSU), species estimated 53% of cattle, 28% of pigs, 16% of sheep and only 3% of goats. The global effectives are summarized in Table 26.

Large farms with more than 200 cattle heads, although representing 2.3% of production units (1.3% in 2009), they concentrate 44.5% of the effective number of heads (37.5% in 2009). Even so, 1/4 of agricultural holdings (31.5% in 2009) have between 1 and 2 cattle heads.

The dairy cattle herd, consisting of 245,5 thousand heads, had a reduction of 33 thousand heads in the last ten years (-11.8%), becoming present in 14% of farms with cattle (7 % less than in 2009), and representing 15.5% of the total workforce (4 % less than in 2009). Among the main milk-producing regions, Entre Douro and Minho and Azores reinforced their position, holding together 72.3% of the national dairy herd (66.4% in 2009), concerning the loss of importance of the other dairy basin - Beira Litoral - in absolute terms (-12.1 thousand heads) and relative (represents 8.3% of the national dairy farm, losing 3.4 %, compared to 2009 and equaling the representation of "Ribatejo e Oeste").

The farm's average dairy herd size is 48.4 head, almost five times the average herd total. The analysis of traditional milk-producing regions (EDM, TM and BL) highlights the region Enter-Douro and Minho for having the highest average herd per farm (62.6 head/farm) and the region of Beira Litoral for presenting the most significant positive variation of the last ten years (more than 2.6 times compared to 2009), thus approaching the average size of the Azorean dairy herd. "Ribatejo e Oeste", although not regions traditionally producing milk, present a significant evolution compared to 2009, starting to hold the largest average size of dairy cattle in the national territory (164 head/farm compared to 70.7 in 2009), thus surpassing the Alentejo, which in 2009 held this position with 45.6 more heads than the average of the "Ribatejo e Oeste".

The usual herd of cattle, which is present on farms throughout the year, amounts to 1.6 million heads. The majority (61.3%) are animals exploited in an extensive regime, which always remain outdoors. On the other hand, of the 626.7 thousand head of cattle housed, it appears that for almost 32.1%, the housing regime is only partial since the average time in the pasture is around 8.7 months.

Regionally, the non-stalled herd is particularly relevant in Alentejo, Beira Interior and Azores, with 87.8%, 86.2% and 84.1% of the total regional pack. Furthermore, in these regions, the number of stables where the animals graze is significant, varying between 42.6% in the Azores and 62.0% in "Beira Interior", remaining in the pasture for more than 7.5 months/annum. On the other hand, in "Ribatejo e Oest", the representativeness of the herd not stabled does not go beyond 39.2%. In "Entre-Douro e Minho", it is relatively marginal (3.3% of the usual regional workforce). Also, for confined cattle, the representation of grazing is lower, representing 37.3% of the stabled cattle population in "Ribatejo e Oeste" and 15.1% in "Entre-Douro e Minho".

Pig production is spread over around 28 thousand farms (50 thousand in 2009), with practically half of the swineherd concentrated in "Ribatejo e Oeste" (44.5% in 2009) in about 5% of the total farms with pigs (6.4% in 2009). On the other hand, the second pig-producing region, "Beira Litoral", has 22.2% of the national swine herd (20.5% in 2009) distributed over 36.0% of the total production units with this herd (38.7% in 2009). The Alentejo, although losing relative and absolute importance in terms of personnel, gathers 1/5 of the total swine herd (24.8% in 2009), present in 5.4% of farms with swine (5.2% in 2009).

The increase in the number of pigs at the national level is mainly justified by the rise in the number of pigs in "Ribatejo e Oeste" (+246.6 thousand heads corresponding to a positive variation of 28.8%) and "Beira Litoral", where this herd grew by about 25%, increasing, compared to 2009, almost 100 thousand heads.

The increase in the average size of the herd on the farm further reinforced the concentration of the sector, in which a small number of pig farms hold a large part of the herd. The data collected in 2019 indicate that much of the pig population (87.4%, compared to 79.7% in 2009) is concentrated in farms with 1 000 or more pigs, representing 1.1% of farms with pigs (0.6% in 2009).

The overwhelming majority (93.7%) are stabled, and this reality is common to the entire national territory since that in the region where it is less important, the Alentejo, this production system still covers 75.0% of the respective regional pig population. The situation is identical when analyzing the breeding stock, with 91.8% of the stabled herd and 70.9% in Alentejo.

Sheep production is an activity that has some concentration at a regional level. The 2.2 million heads censused in 2019 reflect a decrease of 1.7% compared to 2009. This sheep population, present in about 43 thousand agricultural holdings (51.8 thousand agricultural holdings in 2009), is mainly exploited in the Alentejo (52.2% of the total workforce, compared to 49.1% in 2009) in a universe of just over 8 thousand agricultural holdings. The data accumulated with Beira Interior total more than 2/3 of the national sheep population (68.1%) in less than 1/3 of the total farms with sheep (29.9%).

The dairy sheep herd has lost practically 1/3 of its herd (32.9%) in the last ten years. In 2019 it represented 11.3% of the sheep population (16.6% in 2009) and was present in 8.2% of farms (15.4% in 2009). The production of sheep's milk is mainly located in the "Beira Interior", which concentrates 5 5.8% of the dairy herd (52.0% in 2009). Despite the effective reduction of sheep, the average size of the herds has increased since 2009 by almost 20%, passing from 42.9 to 51.1 head per farm. This evolution was even more evident in dairy ewes, with the average per farm growing 42.9%, from 46.1 to 70.2 heads.

The data of 2019 census show that the number of goats registered in 2019 decreased by 11.5% and totalled 372,300 heads (420,700 heads in 2009) exploited in 22,900 farms (32,500 farms in 2009). "Alentejo" holds 23.0% of the total goat population, and the remainder is evenly distributed across the "North", "Centre", "Ribatejo and Oeste" regions.

The dairy goat herd shows a more accentuated decrease (-26.7%) and represents 29.4% of the goat herd (in 2009, the contribution was 35.5%), spread over 4.7 thousand farms (11,9 thousand in 2009). "Beira Interior" and "Alentejo" hold the majority of the dairy herd (51.4% compared to 51.2% in 2009), and in "Beira Interior", more than half (51.8%) of the regional herd is dairy (61. 9% in 2009).

The reduction of the goat herd was accompanied by an increase in the average size of the flocks of 3.3 heads for the total pack (16.3 heads compared to 12.9 heads in 2009) and 10.7 heads for the dairy herd corresponding to an average size of 23.3 heads. Regionally, the average size of herds in "Beira Interior" increased the most (1.5 times compared to 2009), slightly above the national average; in the dairy herd, the highlight goes to "Ribatejo and Oeste", which, in ten years, has doubled the average size of its herds, becoming more than double the national average (47.6 head per farm).

The number of birds accounts for 54.5 million heads (35.3 million in 2009) present in 100,500 farms (161.0 thousand in 2009), that is, 34.5% of the census units in 2019 had birds. This bird population is distributed mainly by the regions of "Beira Litoral" (48.7%, compared to 47.4% in 2009) and "Ribatejo and Oeste" (38.6%, compared to

36.7% in 2009), which already accounted for 87.3% of the total number of birds. It should be noted that in these regions, most units are dedicated to industrial poultry production of the main species (chicken, turkeys, and ducks) and both those devoted to producing eggs and meat, which explains the geographical distribution of the poultry population.

The majority of this population, 34.0 million heads, corresponding to 62.4% of the total birds' population, are broilers (57.3%in 2009), followed by 15.3 million laying and breeding hens (+3.3 million birds compared to 2009), representing 28.1% of the total population (-5.8 pp, compared to 2009). This bird's population is present in the vast majority of farms with poultry (91.2%), with a geographic distribution similar to that of the total poultry population: "Beira Litoral" and "Ribatejo and Oeste" concentrate 83.2% of the total number of chickens. The comparison with 2009 reveals a growth of 1.8 million head in the "Ribatejo and Oeste" region, responsible for more than half of the development of these birds' population.

The concentration of production is also evident in the size of production units. The number of heads of birds per farm is 542 at the national level. In the main producing regions, this indicator rises to 1 009 in "Beira Litoral" (an increase of around 132% compared to 2009) and amounts to 2 629 heads of birds in "Ribatejo and Oeste", almost five times the national average and triple the number calculated in 2009.

The number of broiler chickens and laying and breeding hens operated in an extensive regime is marginal, not exceeding 1.2% and 2.2% of the respective birds' populations, corresponding to 332 thousand hens and 402 thousand broilers. Likewise, raising chickens and broilers in tiny poultry houses is not very expressive, accounting for 4.5% of the chickens and 1.8% of the total number of broilers.

The values found in the census showed that in industrial poultry farming, housing in sheds predominates, with laying and breeding hens being reared mainly in cages and poultry for meat production (chickens, turkeys, ducks) in sheds in production on the ground with litter.

The results obtained by type of installation show that 44.7% of the number of hens in production are kept in improved cages, a system used by only 0.1% of farms with facilities. In broiler chickens, 95.6% of the birds' population is installed on the ground with litter; this system is used by 2.7% of farms with this type of exploitation.

7 - Foreseeable impact of climate changes in the Portuguese agriculture sector

7.1 – General overview

Whenever there is an agricultural activity, we may hear constant complaints from farmers in the face of the vagaries of the weather. Drought is part of the Portuguese farmers' nightmares, even before weather records existed. For many years, the press periodically reports about the lack of rain and the lowering of water levels in ponds or dams. Even though the situation is not new, as Orlando Ribeiro (1978) referred, this irregularity is one of the nightmares of Portuguese agriculture. "*In Portugal, the irregularity of the climate is not conducive to developing agriculture. Clay soils can only be used for summer crops. But it is mainly the irregularity of spring, the most capricious of the seasons, that can compromise production. Spring rains, when scarce, do not help plant development; in excess, they bend and rot; late, coinciding with the high heat of May, favour the development of parasitic diseases. Spring has other dangers: late frosts, days of strong wind that agitates the branches of the flowering trees, not infrequently losing the fruits, sporadic floods of the great rivers, which now harm the plants already grown or delay the beginning of the summer sowing*".

Climate change will accrue the current vagaries of agricultural yields and, consequently, the livelihoods of people who depend on it. Therefore, it is essential to increase the information available so institutions and farmers can assess adaptation mechanisms to reduce these vulnerabilities. Knowing the current situation and foreseeable trends provides a good starting point to cope with present climate variability and address adaptation needs in the context of food security. Learning from experience can help prevent the underachievement of sustainable development efforts and prevent maladaptation. The distribution of impacts will vary depending on the adaptability of solutions implemented to respond to impacts and available resources. Its dependence on physical, social, and economic conditions makes suitable solutions variable between regions and nations. In some cases, impacts will be unexpected and appropriate responses may not be readily known or implemented in advance.

The annual precipitation and temperature cycles (minimum and maximum) in Portugal reveal that warm and dry summers are more pronounced in the southern regions, presenting accrued drawbacks to agriculture. The major one is insufficient rainfall during the spring or early summer seasons. In fact, most of the rainfall occurs during the winter season, from October to December, decreasing for the second quarter (January to March), as depicted in Table 5, pp. 56).

As an essential part of Portuguese soils are poorly drained during the winter, the precipitation concentration coinciding with lower temperatures means a time lag between the rainy and the vegetative growth seasons. This means that the critical water needs of crops occur in spring. On the one hand, the lack of coincidence between radiation and heat and the availability of water in the soil, on the other, limits agricultural productivity and crop yields in Portugal, particularly in the driest regions that do not benefit from irrigation facilities. On the other hand, as has been happening with the increase in rainfall irregularity and its significant decrease in spring, as has been seen in the last two decades, the simultaneous occurrence of a dry winter accentuates the repercussion of water stress, which will have a harmful negative impact in reducing the growth and production of cereals such as wheat, rye, oats, and barley.

Within the project, SIAM II (Cunha[479] et al. 2006) reporting on climate change foreseeable impacts on water resources availability showed a clear tendency for reduction both on surface and groundwater, especially in the centre and south regions of Portugal, with increasing non-symmetric distribution during the year (see Table 7, pg. 75).

This decrease in water availability is also reflected in the significant flow reduction in the rivers of south Portugal, emphasizing the vulnerability of Portuguese agriculture in those regions more prone to the occurrence of drought and the importance of the conservation water resources policies, as well as for the agricultural systems and options to be implemented.

[479] Cunha, L.V., Ribeiro, L., Nascimento, J. (2006) – Recursos hídricos, Chap. 3. In: Santos & Miranda (eds.) *Alterações Climáticas em Portugal. Cenários, Impactos e Medidas de Adaptação*. Projeto SIAM II. Gradiva, Lisboa

7.2 - Foreseeable impacts in food security

Compared to other economic sectors, agriculture is disproportionately exposed and vulnerable to adverse natural hazards, especially climate-related ones. Climate change drives short-term shocks, such as extreme weather events, and generates slow-onset stresses, such as higher temperatures, droughts, and biodiversity loss. Shocks have an immediate impact, while stresses are slow processes that gradually undermine the capacity of systems to cope with change, rendering them more vulnerable. Food security is complex due to its multiple dimensions and should not be confused with food production. Assessing the impact of climate change on food security is therefore particularly challenging, as it results from a complex of estimates that involve four primary sources of uncertainty: the emissions scenario, the climate scenario, the induced variation in crop yields and cultivable area, and the impact on food safety.

Agri-food systems' components and actors are exposed to shocks and stresses of various types and intensities. Because components are interlinked, any disruption can spread quickly throughout systems. The same shock or stress may impact different systems' features and actors differently. Among producers, shocks are most likely to affect the livelihoods of low-income, small-scale operators; among food consumers, the poorest will be the most affected by rising food prices.

Population and income growth are two well-known factors that drive demand for food and cause changes in people's food preferences. Persistent pockets of poverty, inequality and unemployment restrict access to food and hinder the achievement of food and nutrition security objectives worldwide. It should be noted that agricultural production is limited not only by the depopulation and ageing of inland areas but also by the growing scarcity and diminishing quality of land and water resources and insufficient investment in sustainable agriculture. Climate change is making itself felt more visibly and increasingly affecting rural incomes and livelihoods as agriculture continues to emit greenhouse gases (GHGs).

In this unfavourable context, there is an evident lack of basic information on the projections of the impacts of climate change on the socio-economic system where the main drivers are found - population and per capita income. The reflections made here are aimed at alerting to global trends as well as an alert to the need for integrated studies in this area, as well as an alert to our weaknesses in this matter. Risk management strategies that reduce exposure and vulnerability to a known specific shock - such as drought preparedness - and clear policy willingness support by well-endowed financial instruments are necessary to help build agri-food systems' resilience in Portugal.

In the current conditions, the impact of climate change and the structural flaws of the Portuguese agricultural sector should negatively affect all aspects of food security (availability, access, use and stability of food), leading to complex impacts on Portuguese food security that will be further affected by the global pressure that is already occurring (Table 27).

Table 27 - Relationships between food security, climate change and food system

Food security pillars	Climate change impacts	Potential adaptation and mitigation strategies
Availability	Reduced yields in crop and livestock systems	Development and implementation of adapted practices; increased yields through breeding, enhance production technology and management, stabilise land tenure regimes
	Reduced yields from changes in culture's growth cycle, lack of pollinators, pests & diseases	Enhance resilience, introduce new adapted varieties, make adaptation in culture calendars, adoption of new technologies
	Reduce food quality affecting its nutritional composition or its availability	Directed breeding, enhance quality and resilience by integrated post-harvest technologies, better food storage
	Disruptions to food storage or transport networks	Right management of critical storage provisions, reduction of food waste; diets modifications
		Closing of crop yields and livestock productivity gaps
		Enhance risk management including developing marketing and financial mechanisms and food aid
Access	Yield reductions, changes in farmer livelihoods, inability to purchase food	Integrated agriculture practices to build resilient livelihoods
	Price rise and spike effects on low-income family consumers	Increase and improve supply chain efficiency, reducing food waste
	Effects of increased extreme events on food supplies, disruption of agricultural trade and transportation infrastructure	More climate resilient food systems, market changes, improve supply chains efficiency, dietary changes policies
Utilisation	Impacts on food safety due to bad storage leading to increased microorganisms and toxins	Improved storage and cold chains, improved efficiency of food processing adequate food handling and transport
	Decline in nutritional quality from increasing atmospheric CO_2	Adapted improved crops, widespread healthy diets, enhanced cooking, and food preparation
Stability	Greater instability of supply due to increased severity and frequency of extreme events, food price rises and spikes, instability of agriculture incomes	Resilience via integrated systems and practices, diversified local agriculture, infrastructure investment, empowerment of local agriculture organizations, transparency of food chains and external costs
	Widespread crop failures, instability to land access; generalised army conflict	Crop insurance for farmers, institutional build up to planning and prediction seasonal and inter-seasonal climate risks

Table 27 - Relationships between food security, climate change and food system (cont.)

Impacts resulting from interactions with the four food pillars	Increasing poverty and undernour-ishment as food systems are negatively impacted by climate change	Increase food systems productivity, and acting in the supply side through government action and institutional responses
	Increasing health problems (e.g. obesity, stunting, child mortality)	Increase production of healthy food, develop smart food systems by reducing GHG

Source: Mbow [480]et al. (2019)

As production possibilities shift across agroecological zones, global agricultural trade flows will, with high probability, shift dramatically. The medium-term projection prepared by the United Nations (2011), considering population growth for 2050 (9.3 billion people), combined with the significant changes that occur in the replacement of the cereal-based diet with increased consumption of meat products, is reflected in a substantial increase in pressure on natural resources, global food supplies and rising prices. Indeed, technological innovations generate new opportunities to increase income even further. Yet these possibilities are limited by global environmental changes, including soil degradation, changes in hydrological regimes and water scarcity that limit the significant extent of irrigated agriculture.

The land available for food production will be even more threatened by increasing competition from other land uses, as we have seen in Portugal with the increase in large agricultural areas for intensive irrigated olive and almond groves in areas very subject to aridity in Alentejo and forest areas cleared for the installation of solar collectors for energy production.

Global food production potential is likely to increase as long as the minimum growth factors for each crop are met, with the global average temperature rising to about 3 °C. Still, above that, it is very likely to decrease.

Food and forest products trade is projected to increase in response to climate change, with increased food-import dependence in most developed and developing countries (Parry et al., 2007). Studies suggest that agricultural trade facilitates adaptation, brings global welfare benefits, and emphasises the importance of removing trade distortions, e.g. subsidies (Huang[481] et al., 2010).

However, others (e.g., Cline[482], 2007) point out that limited buying power would severely constrain adaptation in developing countries through increasing trade. So, the number of people at risk of hunger due to climate change will depend on overall socio-economic development.

---

[480] Mbow, C., Rosenzweig, C., Barioni, L.G., Benton, T.G., Herrero, M., Krishnapillai, M., Liwenga, E., Pradhan, P., Rivera-Ferre, M.G., Sapkota, T., Tubiello, F.N., Xu, Y. (2019) – Food Security, 437-550. In: Climate Change and Land: an IPCC special report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems [(eds) P.R. Shukla, J. Skea, E. Calvo Buendia, V. Masson-Delmotte, H.-O. Pörtner, D.C. Roberts, P. Zhai, R. Slade, S. Connors, R. van Diemen, M. Ferrat, E. Haughey, S. Luz, S. Neogi, M. Pathak, J. Petzold, J. Portugal Pereira, P. Vyas, E. Huntley, K. Kissick, M. Belkacemi, J. Malley].

[481] Huang, H., von Lampe, M., and van Tongeren, F. (2010) – Climate change and trade in agriculture. *Food Policy* 36: 9-13

[482] Cline, W.R. (2007) – Global warming and agriculture: impact estimates by country. Peterson Institute for International Economics. Washington, DC, USA.

Smallholder and subsistence farmers, pastoralists and artisanal fisherfolk will suffer complex, localized impacts of climate change.

Although the magnitude of the impact on global agricultural production is uncertain, countries in the temperate zones of North America, Northern Europe and Asia are expected to benefit from increased agricultural productivity. In contrast, regions around the Mediterranean, including Portugal and especially in tropical zones, are expected to be net losers due to the predictable decline in land productivity.

For most developing countries in semi-arid, arid, and tropical zones, yields are expected to drop significantly, reducing current production levels, and making it more challenging to reach the even higher productivity goals needed to meet their growing food demands in the following decades.

This disruption in global agriculture will also be potentiated as the world population during the next 34 years rises to a projected 9.1 – 10 billion in 2050, with most of the additional 2 billion people living in developing countries, which requires that agriculture significantly step-up production and productivity in the coming decades. At the same time, more people will be living in cities (70 per cent against the current 50 per cent). Urbanization and rising incomes in developing countries are driving increases in the consumption of animal products (FAO[483], 2009).

Given these trends, Searchinger[484] et al. (2019) estimates that production will have to increase by 60 per cent by 2050 to satisfy the expected demands for food (+50%), and animal-based foods (≈70%) and feed. Yet even today, hundreds of millions of people remain undernourishment as agricultural systems and country institutions fail to guarantee enough food and conditions to allow equitable distribution of available food.

Without sufficient adjustment by existing agricultural systems, the number of people living in hunger will rise rapidly over that period. For example, a recent study suggested that without adaptation efforts, decreased yields in South Asia could threaten the food security of more than one billion people, and the number of malnourished children in Africa could increase by 10 million more to a total of 52 million by 2050. The rate of population increases is likely to be higher than the capacity to increase agricultural productivity to satisfy a projected increase of demand (+50%) (FAO[485], IFAD, UNICEF, WFP, WHO, 2023) means a high likelihood of food prices aggravating poverty, hunger, and undernourishment. Thus, climate change is expected to negatively impact all four dimensions of food security: availability, stability, utilization, and access.

The combined effect of increased demand and the foreseeable reduction in yields due to climate change is an explosive combination that will inevitably be reflected in the rapid increase in agricultural commodity prices. If the world already struggles to meet basic human needs, the challenges ahead will be significant. The first two decades of the 21st century have seen several harbingers of a troubled future for global food security. The rise in food prices in 2008, with the consequent food riots and consequent political changes in several countries, aggravated today by the difficulties in accessing cereals and sunflower seeds due to the Ukraine-Russia war, awakened world leaders to the resurgence of this threat to human well-being and social harmony.

---

483 FAO (2009) – The state of food and agriculture: livestock in the balance. FAO, Rome

484 Searchinger, T., Wait, R., Hanson, C., Ranganathan, J., Dumas, P., (2019) – Food Future. A Menu of Solution to Feed Nearly 10 billion People by 20250. Final Report. WB, UNEP, UNED, CIRAD & INRA. 554 pp.

485 FAO, IFAD, UNICEF, WFP and WHO (2023) - *The State of Food Security and Nutrition in the World Urbanization, agrifood systems transformation and healthy diets across the rural–urban continuum*. Rome, 285 pp [doi.org/10.4060/cc3017en]

Predictions for the world prices for the most important crops with no climate change were that rice, wheat, maize, and soybeans would increase between 2000 and 2050, driven by population and income growth and biofuel demand. Even with no climate change, the price of rice would probably rise by 62 %, maize by 63 %, soybeans by 72 %, and wheat by 39 %. Climate change will likely result in additional price increases - 32 to 37 % for rice, 52 to 55 % for maize, 94 to 111 % for wheat, and 11 to 14 % for soybeans. If CO_2 fertilization is effective in farmers' fields, these 2050 prices would probably be 10% smaller. In the IMPACT model, livestock is not directly affected by climate change (Nelson[486] et al., 2009), but the effects of higher feed prices caused by climate change pass through to livestock, resulting in likely higher meat prices. For example, beef prices will likely be 33 per cent higher by 2050 with no climate change and 60 per cent higher with climate change and no CO_2 fertilization of feed crops. With CO_2 fertilization, crop-price increases are less, so the beef price increase is about 1.5 per cent less than without CO_2 fertilization.

Because the disruption of agricultural production is expected to be most severe in the Mediterranean region, including in Portugal, their import food requirements and their import financing needs will increase substantially. Thus, the expected effects of climate change on global agricultural production will have severe and negative impacts on food security for many countries in the Mediterranean rim and Portugal.

7.2.1 - Synopsis of main climatic constraints to agriculture

Despite the difficulty to make a synthesis of the results available from different observation periods, data, and methods, there is a common convergency about the following:

a) There is a generalized rainfall decrease in Portugal. Except for very small regions comparison of 1913/14 to 1967/68, shows the country faced a decline above 120 mm. In the northwest wettest region, such a decrease exceeds 500 mm. In year terms, it represents a mean trend value of -4.27 mmy^{-1} for the 106-year period compared with 0.89 mmy^{-1} for 1913/14 - 1967/68 and -11.42 mmy^{-1} for the interval of 1968/69 - 2018/19.
b) Considering the more extended 106-year rainfall data set, a spatial pattern trend was found, with each month showing almost the same negative rainfall trend over the country, except for October.
c) The homogeneous negative rainfall trends behaviour is a clear indication of the vulnerability of Portugal concerning water availability and its agriculture sector that is its leading consumer.
d) As for temperature changes, it was found that in 1976/2008, the maximum temperature rose by 0.41 ºC/decade and the minimum by 0.30 ºC/decade. In contrast, the cold spell duration index (CSDI) has decreased significantly over the last 20 years, from 1988/to 2008.

In mainland Portugal, the resolution of the most extensive simulations available on the Climate Portal, considering various socioeconomic and emission scenarios, present projections for the end of the XXI century of an increase in average air temperature of

[486] Nelson, G.C., Rosegrant, M.W., Koo, J., Robertson, R., Sulser, T., Zhu, T., Ringler, Claudia C. et al. (2009) – Climate Change Impact on Agriculture and Costs of Adaptation. International Food Policy Research Institute, Washington, DC. 30 pp.

1.85 ºC (RCP4.5) to 4.29 ˚C (RCP8.5) and decreased precipitation in mainland Portugal about 5% (RCP4.5) to 15% (RCP8.5), especially in the South, where the reduction maybe 30%. The impact consequences on water resources could not be more expressive.

e) Although, with a significant variation from 1976 (the start of the warming period), the number of tropical nights per year has shown a clear increase. The average values for Lisbon station showed average values for values around 20 by the end of the 20th century.

f) Another good indicator for country warming is the number of days per year or season above a specific threshold temperature (in our case, 25 ºC). Climate change simulations carried out under the SIAM II project showed that both spring and autumn have a significant number of days above the 25 ºC threshold, implying a substantial increase in the annual average frequency of "summer days" to 120 days in the north, 150 in the centre and more than 180 in the interior south.

g) The change in the number of "hot days", with maximum temperature above 35 ºC, is even more significant to agricultural activities. In the control simulation, the number of "hot days" is only meaningful in the interior south, where this number surpasses 20 days. That number dramatically increases in the climate change scenario with maximum values of more than 90 days in the same interior south region. The increase in the rest of the country is also very significant. These high values could dramatically decrease agriculture productivity if they occur in particular cultures' specific growth cycles. See, for example, this effect in the fruit set percentage (Fig. 46).

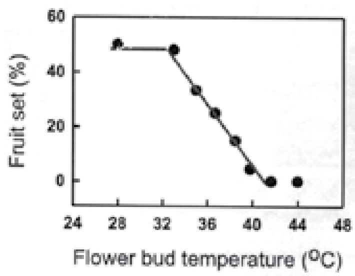


Fig. 46 – Effect of flower bud temperature in fruit set percentage
Source: Wheeler[487] (2013)

h) Projections of rainfall under two scenarios, RCP 4.5, and RCP 8.5, for the period 2071/2100 showed for the first one that most of the mainland will suffer a decrease of 5% concerning the 1971- 2000 period, while mainly in the south this reduction will be around 15%. The forecast is much more severe for the second one as a large part of the territory will suffer a sharp decrease between 25% in the south and centre and part of the northeast and 15% in the north.

i) The combined effect of the reduction in rainfall and the increase in temperature is reflected in the growth in evapotranspiration (difference concerning the 1971-2000 mean values), which increases from +77mm under scenario RCP 4.5 to +184 mm for scenario RPC 8.5, which further enhances the predictability of a significant increase in the risks of aridity of the territory with its probable consequences in decreasing of agriculture productivity.

[487] Wheller, T (2013) – Climate change impacts on global food security. University of Reading. 24 pp

j) The Palmer Aridity Index (PDFI) analysis, an excellent tool to predict some of the vulnerability Portuguese agriculture faces, is evidence of how Portuguese agriculture is highly dependent on water availability. The situation already shows strong signs of concern, as there is an increase in land under the semi-arid classification, which rose from 28% (1960/90) to 45% (2000/10). As for the Dry or Arid land areas, we see that they went up for the same periods from 36% to 63%. For the Portuguese Atlantic region, usually more humid, it decreased from 64% to 37% for the same period.

k) Considering climate change's foreseeable impacts on water resources availability, the tendency for surface and groundwater water reduction is evident, especially in Portugal's centre and south regions, with increasing non-symmetric distribution during the year. This decrease in water availability is also reflected in the flow reduction in the rivers, which is more pronounced in the south of Portugal, emphasizing the vulnerability of Portuguese agriculture in those regions more prone to the occurrence of drought spells and the importance of policies for the conservation of water resources, as well as for the development of conservative agricultural systems options that must be drawn and implemented.

l) Due to its geographic location, mainland Portugal is prone to frequent drought episodes, with the south being the most vulnerable area. The analysis of the PID index (periods of intense drought) shows that the driest years of the series started in 1941, when 56% of the territory happened to be in severe drought and 24% in extreme drought at the end of the 1945 dry period. Since 1980, however, there have been nine occasions when more than 10% of the mainland has been in extreme drought, and in four following times, more than 75 % of mainland Portugal was in severe or moderate drought. Analysis of drought anomalies from 1931 to 2017 showed increased frequency and intensity, affecting more parts of the country. This increased vagaries of heat waves and rainfall underline the vulnerability of Portuguese agriculture activity and its increased dependence on water to sustain farmers' livelihoods.

m) Such behaviour of decreasing rainfall and observed warming increases reinforce the difference between the north region, less wet but still wet, and the south becoming drier with evidence of increased aridity. This trend agrees with the widespread tendency mentioned by Hoerling[488] et al. (2012), which refers to the overall drying trend across North Africa and southern Europe, extending from the Atlantic coast to the Middle East. It is also concurrent with the northward shift of homogeneous agroclimatic zones and the corresponding change in crop growth suitability to grow specific crops.

n) The observed warming also has the potential to promote the shift of crop species to previously constrained areas by either a too-short growing season length or insufficient thermal requirements to finish the crop growth cycle.

Considering the trends in the Portuguese's climate evolution, the question that arises is knowing to what extent the productivity of agriculture will be affected, increasing the vulnerability of the supply of food products to its population, bearing in mind that Portuguese agricultural balance is already markedly in deficit and that the international market that covers this deficit has been under severe pressure, not only because of the demographic increase and increased meat consumption in Asia but also because of the climate changes that have been affecting countries with surpluses in agricultural products.

---

[488] Hoerling, M., Eischeid, J., Perlwitz, J., Xiaowei, Quan, Zhang, Tao, and Pegion, P. (2012) - On the Increased Frequency of Mediterranean Drought. *Journal of Climate*, 20: 2146-2161

Concerning Portugal, results shown by Pinto[489] et al. (2006) using GCM (large scale) and regional (intermediate scale) climate change models GCM FAO-CERES for crop yields refer to a drastic reduction in yields for crops like wheat and maize (up to -50 %) and even more for rice (up to -75 %). Pasture and fodder crops are the only group that may increase yields (up to +75 %). Valverde[490] et al. (2014) analysing climate change impacts on crop yield in the Guadiana basin (historical period 1960-2010), observed similar decreasing productivity trends, although with lower absolute values.

These values for wheat and maize are more moderate in the more integrated study of Brandão (2006) that showed for maize a productivity decrease in the range of 12-23 % and a decrease for wheat in Elvas region of -20%, and an increase in Braga region in the north.

The simulation study of Abd-Elmabod[491] et al. (2020) for Andalusia (Southern Spain) using the so-called Terraza and Cervatana models showed, notwithstanding some weaknesses of the model, highly dependent on bioclimatic data on crop parameters, yield reduction for the two major rainfed crops (wheat and sunflower), since irrigated areas in Andalusia represents only 10 % of agriculture land.

For sunflowers, yield reductions varied between slight (≈ -10 %) for better soil units to extreme cuts up to -80 % for worse land use capabilities for this culture. The climatic periods of 2070 and 2100 present more yield reduction than the current and 2040 periods. Sunflower (a summer-grown rainfed crop) proved very sensitive to future climate changes in 2040, 2070 and 2100. In general, even under current conditions, the sunflower crop is threatened by the reduction in its yield, as only 51 % of the study area (87600 km2) is resistant to yield reductions. Projections for 2040 showed that around 22% of the sunflower-cropped area would resist the impacts of climate change. In 2070 and 2100, only about 5 % of the sunflower crop area would experience no yield reduction. The remaining areas suffered a decrease between 50 to 80 %, primarily because of the water deficit.

Much lower yield reductions are predicted for wheat, which was negligible except for a few regions when analysed under the A1B climate change scenario. For wheat in 2040, 2070 and 2100, only 2,6 and 10 % of the study area experienced yield reduction, whereas the rest of Andalusia does not show yield reduction. The observed affected areas were restricted to Almeria province, and the results may be due to land capability soils under cultivation. However, wheat is anticipated to be partly affected, with a foreseeable yield reduction of up to 36 % between 2040 and 2100 in some soil units.

Considering the geographic proximity of Southeast Alentejo to Andalusia, we believe that the decreasing trends in sunflower yield and wheat productivity will have an expression of the same order of magnitude in Alentejo.

For southern Portugal (Guadiana River basin), Valverde[492] et al. (2015) working with five climate scenarios (CCS 1-5) and 3 future emissions scenarios (A2, B1, A1B) defined through the

---

[489] Pinto, P. A. Braga, R., Brandão, A. P. (2006) – Agricultura, Chap. 5. In: Santos & Miranda (eds.) *Alterações Climáticas em Portugal. Cenários, Impactos e Medidas de Adaptação*. Projeto SIAM II. Gradiva, Lisboa

[490] Valverde, P., Serralheiro, R., Carvalho M., Shahidian, S., Rodrigues, C. (2014) – Efeitos das alterações climáticas nas necessidades úteis de rega na bacia do Guadiana. Ver. Recur. Hídricos. Lisboa APRH 35 (1): 53-67

[491] Abd.Elmabod, Sameh, Muñoz-Rojas, M., Jordán, A., Anaya-Romero, M., Phillips, J. D., Laurence, J. et al. (2020) – Climate change impact on agricultural suitability and yield reduction in a Mediterranean region. *Geoderma*. journal homepage: www.elsevier.com/locate/geoderma.

[492] Valverde, P., Serralheiro, R., Carvalho, M., Maia, R., Oliveira, B, Ramos, V. (2015) – Climate change impacts on irrigated agriculture in Guadiana River basin (Portugal). *Agriculture Water Management* 152: 17-30

combination of rainfall and air temperature changes relative to the historical period 1961-1990 showed that:

a) Average annual rainfall for A2 emission scenario was between 515 mm (CCS 2-5) and 552 mm (CCS 4), falling under a more adverse emission scenario B1 to 438 (CCS 2) and 517 mm (CCS 4).
b) The average daily ETo for 1961-1990 revealed an average value that ranged between 3.29 - 3.40 mmday^{-1}. Future output projection 2011-2040 under the A2 emission scenario did not vary far from the previous period, standing within the 3.23 and 3.27 mmday^{-1} range. During the simulation period, it was found that although the overall mean temperature $_{Tmed}$, T_{max} and T_{min} increased over time in both future periods, the ETo did not return a significant ETo trend, probably due, as suggested by the authors, that in the simulations the T_{min} increased faster than T_{max}, thereby decreasing over the years, both the thermal difference used in the calculation of ETo values, reducing its reliability for distant future periods. This shows that the reliability of projections of the behaviour of some parameters that are important in calculating the impacts of climate change on agriculture still has a long way to go.
c) Irrigation requirements to supply the complete implementation of the Alqueva irrigation network project areas for the representative crops will reach a maximum of 875 hm3year^{-1} for the 30-year period (2011-2040). This value is about three times higher than the historical agricultural situation for each changing scenario studied. This volume of irrigation water is expected to reach 966.8 hm3year^{-1} for the future period 2041-2070 for the most severe climate scenario. When comparing the values of the Water Exploitation Index (Table 29), it seems to be possible to conclude that the plans for a significant extension of the irrigated area and the intensification of irrigated agriculture and agriculture options very demanding in water must take seriously the seemingly undeniable trends of reduced rainfall, increased temperature, and the indicators of a clear increase in aridity in Alentejo.

Although the focus of the study mentioned was the agricultural sector because it is the economic sector where water demand is dominant, the study authors (Valverde et al., 2015) make a warning that should be looked at with great concern by territorial management policy authorities to the need for widespread public awareness and participation towards common water-saving practice "*it is important to bear in mind that climate changes consequences on water demand in a future water scarcity scenario to go well beyond agriculture, requiring a multidisciplinary team for addressing all aspects of planning, management policy development, monitoring and evaluation enforcement, to accomplish an equitable allocation of water resources between all-consuming sectors, including the domestic uses, energy generation and ecological management*".

In the water-poor Mediterranean region and Portugal, while people have always had to deal with scarcity and develop adaptation strategies to meet their most essential needs, existing adaptation capacities are being stretched to the limit, threatening to increase the number of people with a water deficit. The MedECC[493] study (2019) mentions that water scarcity in Mediterranean region is expected to increase from 180 million in 2013 to more than 250 million by 2030.

[493] MedEEC (2019) – Climate and Environment Change in the Mediterranean – Main Facts. MedECC (Mediterranean Experts on Climate and Environmental Change. https://www.medecc.org

Addressing water shortages and water scarcity is a prerequisite to achieve the 17 SDGs. Mediterranean countries are generally not on track on achieving the SDGs (Fig. 59), with an average value of the SDG Index (71.6/100), which would locate the region around the 49^{th} position in the global ranking (Antonelli[494], 2021).

Bindi[495] and Moriondo (2005) studied the foreseeable impact of climate change on agriculture for the Mediterranean countries for SRES-IPPC scenarios A2 (medium-high GHG emission 520 ppm CO_2) and B2 (Medium-low GHC emission 470 ppm) for two period 1961-1990 (CO_2 at 350 ppm) considered to represent present climate and 2031-2060 the future climate. They used the HadCM3 model for the daily climate data simulation and the CropSyst to reproduce crop yields based on data reported by FAOSTAT focusing on photosynthesis of C3 and C4 summer crops, winter and summer crops and food composition and their extension and importance in each MED countries. Simulated values from CropSyst were calculated for individual grid cells, while statistical FAO data was collected at the national level.

Results considering CO_2 fertilizing effects are set forth in Fig. 47. All of the crops were considered fully fertilized (i.e. no nitrogen stress) including CO_2 effects.

Concerning Portugal crops chosen were: Maize (C4, summer crop); sunflower (C3 summer crop), legumes (bean), tuber crop (potato), cereals (wheat). In the CropSyst runs maize and potato were treated as irrigated crops whilst the rest of the crops were considered rainfed crops.

The same authors found that in the warmer southern Mediterranean, increases in CO_2 help reduce the loss in yield arising from a warmer and drier climate, but they cannot offset the losses.

In cooler north-western and north-eastern Mediterranean, CO_2 increase, and the associated climate change show a little net effect on crops analysed, provided that the increased water demands, especially for irrigated crops, can be provided. As for rainfed summer crops, a net reduction in yield is expected even when CO_2 fertilisation effected is considered (Table 28).

Despite the importance of the predictive value of these simulations, one should note that these are single snapshots of future impacts, thereby lacking the temporal and causal dynamics that characterise actual responses in farmers' fields.

Despite the importance of the predictive value of these simulations, one should note that these are single snapshots of future impacts, thereby lacking the temporal and causal dynamics that characterise actual responses in farmers' fields.

---

494 Antonelli, Marta (2021) – The Water-Food Nexus in the Mediterranean Region: Prospects and Challenges for Sustainability, 25-53 pp. In: Dessi, A., Fattibene, D. and Fusco, Flavia (eds). Climate Change and Sustainability: Mediterranean Perspective. IAI Research Studies 6. Instituto Affari Internazionali (IAI), 135 pp.

495 Bindi, M and Moriondo, M. (2005) – Impact of a 2 ºC global temperature rise on the Mediterranean region: agriculture analysis assessment. 54-66 pp. in: Giannakopoulos, C., Bindi, M., Moriondo, M., LeSager, P, and Tin, T (eds), *Climate change impacts in the Mediterranean resulting from a 2 ºC global temperature rise*. WWF Report, 66 pp.

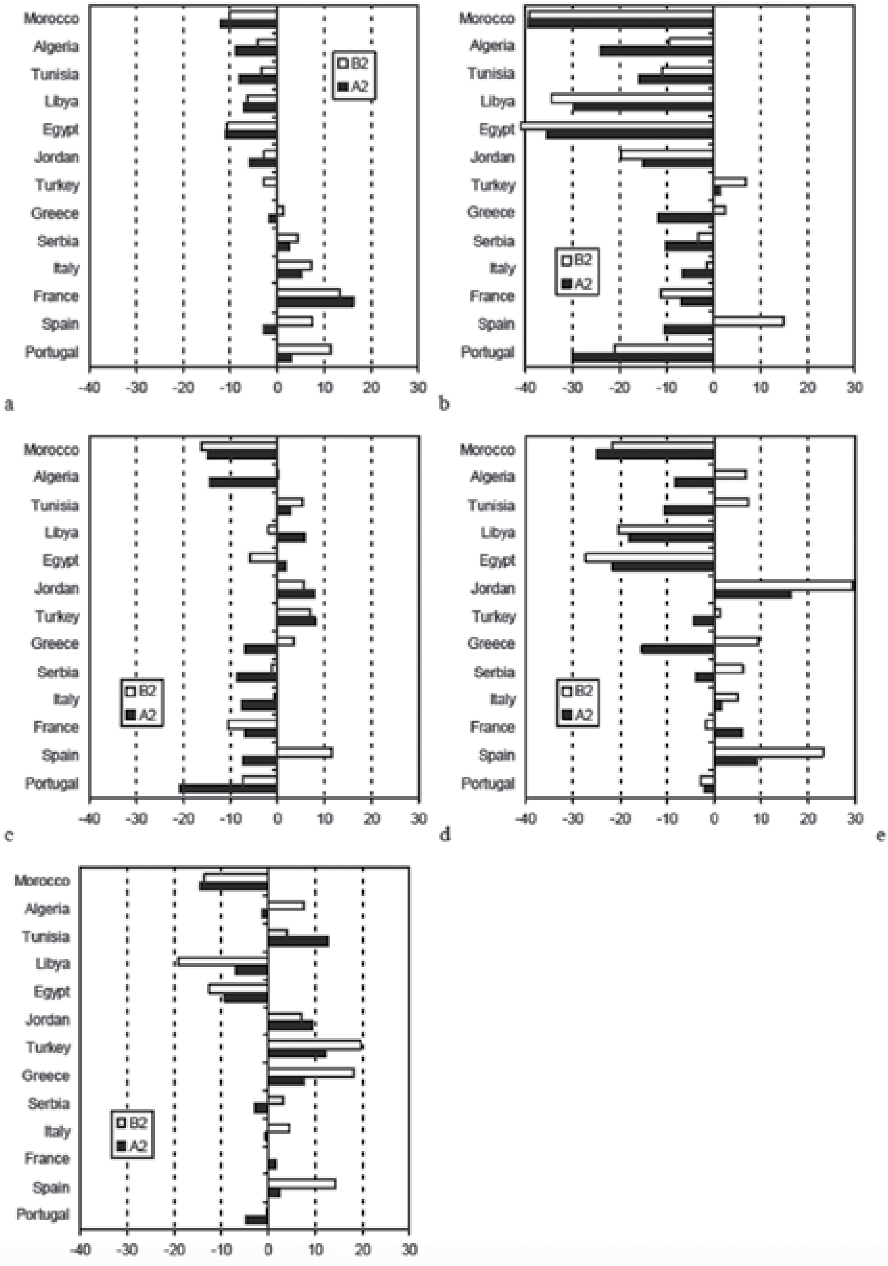


Fig. 47 - Foreseeable impacts of climate change on crop yields (CO_2 fertilizing effects included): a) C4 summer crops; b) legumes; c) C3 summer crops; d) tuber crops; e) cereals. Values are expressed as a % of the differences between average future yields (time slice 2031-2060) and current yields (time slice 1961-1990 according FAOSTAT database).

Source: Bindi and Moriondo (2005)

Table 28 – Percentage change of crop yields for the main Mediterranean regions

Crop type	Growing days	Region	Without CO_2		With CO_2	
			A2-A	B2-A	A2-A	B2-A
C4 summer	126.3	N-W	0.19	5.80	4.19	8.78
		N-E	-4.43	-2.54	-0.60	0.21
		S-E	-11.44	-9.26	-7.89	-6.70
		S-W	-12.87	-8.94	-9.38	-6.37
C3 summer	131.2	N-W	-24.90	-13.42	-14.38	-4.86
		N-E	-18.50	-8.11	-7.19	0.97
		S-E	-32.72	-36.43	-23.30	-30.15
		S-W	-33.26	-25.81	-23.92	-18.48
Legumes	108.0	N-W	-21.79	-10.44	-12.41	-2.85
		N-E	-15.57	-6.92	-5.44	0.96
		S-E	-7.44	-8.19	3.66	-0.41
		S-W	-19.94	-11.81	-10.33	-4.34
Tuber crops	170.4	N-W	-10.37	-4.24	4.87	7.53
		N-E	-22.50	-6.80	-9.33	4.39
		S-E	-18.22	-15.77	-4.31	-5.66
		S-W	-25.88	-12.10	-13.28	-1.55
Cereals	214.0	N-W	-10.97	-3.49	-0.29	4.68
		N-E	-6.79	3.71	4.39	12.49
		S-E	-15.08	-17.17	-4.88	-10.15
		S-W	-13.77	-11.29	-3.42	-3.77

N-W (Portugal, Spain, Franc and Italy); N-E (Serbia, Greece and Turkey);
S-E (Jordan, Egypt and Lybia); S-W (Tunisia, Algeria, and Morocco)
Source: Bindi and Moriondo (2005)

Regardless of its generic values, they delimit the amplitude of the anticipated importance of the impacts. When extrapolating these values, it is necessary, however, not to forget the complexity of agricultural systems and the size of the sites chosen for the studies that are almost always limited, as well as the parameters considered are restricted due to practical reasons of cost and time that need to be taken in consideration. Thus, it is almost impossible to assess all the impacts on agricultural activities carried out in a country or region in studies of this nature, namely when the institutional framework and the political structure organization are highly fragmented and poorly financed and coordinated, as is the case in Portugal.

In fact, trying to quantify the impacts of climate change is a serious challenge that is beyond the scope of this review work, mainly due to the global scale of the likely effects, the diversity of agricultural systems, even in a relatively small country but with a great land-use capabilities diversity and microclimates, socio-economic conditions, and the necessarily long time to obtain reliable information.

8 – Adjusting to climate change

As above mentioned, agriculture is exposed to considerable challenges posed by changes in climate, environment, demography, policy, technology, consumer preferences and trade. Farmers, agricultural policymakers, decision-makers in international organisations, and supply chain managers need evidence and guidance to respond to these challenges and take informed decisions (Haigh[496] et al., 2018). So, understanding social-environmental systems and their dynamics is critical to sustainably managing agricultural and natural resources, effectively utilising synergies, and gradually reducing trade-offs (Messerli[497] et al., 2019).

Climate change is a growing threat to our food systems, with impacts becoming increasingly evident. Rising temperatures, changing precipitation patterns, and extreme weather events, among other effects, are already reducing agricultural yields and disrupting food supply chains. If rising climate change trends are not decreased, it is foreseeable that by 2050, climate change is expected to put millions of people at risk of hunger, malnutrition, and poverty.

Added to this are changes in the interannual variability of income resulting from extreme climate events, which many authors see as an essential factor in food insecurity, undermining the resilience of food systems and affecting the stability of availability and access to food (IPCC, 2014).

The goal of ending hunger will remain elusive even by 2050, especially considering the additional impacts of extreme weather events, local shocks, and global crises, such as COVID-19, the current war in Ukraine, and protracted crises in the Middle East, Sudan and Somalia due mainly to armed conflicts that will push many more people into poverty and hunger. Thus, beyond its direct impacts on production, climate change will create cascading effects on livelihoods and sustainability through interconnections among economic, environmental, social, and political spheres.

Food insecurity, aggravated by frequent and protracted episodes of drought, and the slow development of the agricultural sector, have been at the root of recent social and political unrest in southern and eastern Mediterranean countries, with known consequences affecting far beyond the region. Multi-climate change dimensions – agriculture yield losses, soil degradation and depletion, forest fires, water scarcity, food cost increases and price instability pressures – turn more vulnerable Mediterranean food systems. These are compounded by social tensions resulting from massive youth unemployment levels and the co-occurrence of economic slow-down in the North and demographic growth in the South that provides an explosive mix, calling for urgent integrated technological and policy measures. EURAGRI[498] board (2015) recognizes these risks and urgency when it says that "*Countries from the South and the North share challenges faced by the Mediterranean agriculture and food systems. The Mediterranean is like a magnifying mirror*

---

[496] Haigh, T., Koundinya, V., Hart, C., Klink, J., Lemos, M., Mase, A.S., Prokopy, L., Singh, A., Todey, D., Widhalm, M. (2018) - Provision of climate services for agriculture: public and private pathways to farm decision-making. *Bull. Am. Meteorol. Soc.*, 99: 1781-1790.

[497] Messerli, P., Kim, E.M., Lutz, W., Moatti, J.P., Richardson, K., Saidam, M., Smith, D., Eloundou-Enyegue, P., et al. (2019) - Expansion of sustainability science needed for the SDGs. *Nat Sustain*: 1-3.

[498] EURAGRI (2015) – The challenges for the Mediterranean countries. *New Medit N.* Editorial: 2-3

for all Europe: the concerns about sustainable food systems, inclusive growth, striving rural areas, giving hope to the youth through employment opportunities, and about how to engage globalisation best, are shared concerns, only more acute in the South. Testing robust and adapted solutions in the South will provide invaluable experience and references before challenges become unmanageable in the North".

Adaptive capacity concerning the current climate is dynamic and influenced by changes in human capital, information and technology, material resources and infrastructure, institutions, wealth, and entitlements, which is difficult due to our fragmented research system and multiple centres of uncoordinated governmental decision-makers. These conditions make the calibration and validation of models for the regions and the choice of the most appropriate agricultural techniques to ensure increased predictivity capabilities and confidence in the results obtained with the models quite tricky.

Concluding on the initial question about the potential effects of climate change on agricultural production and the vulnerability of the food system, we would say that as far as we have managed to investigate, we have not found updated in-depth studies that go beyond the approach limited to some regions of Portugal and almost all directed to the question of productivity. Even this is hardly generalizable in terms of the country. At the world level, many authors who have studied food security concerning climate change acknowledge that socioeconomic factors are more likely to determine food security in the coming decades than climate change would (Esterling et al., Kang[499] et al. 2009, Tubiello[500] et al. (2007).

On the horizon looms the stability of whole food systems that may be at risk under climate change because of the low resilience of the system that is vulnerable to short-term variability in supply. The consequences can be highly adverse: factors of production are underused, productivity is low, food and non-food agricultural output are lost, and access to lucrative markets is blocked. Amplifying agri-food systems' vulnerability to multiple shocks and stresses undermines the capacities of actors to prevent, anticipate, absorb, adapt, and transform. Once resilience capacities are compromised, the likelihood of acute and chronic food insecurity and malnutrition increases. Adding up to this susceptibility of the food system, we must remember that globally 90 % of humanity's energy intake is concentrated in only 15 crops grown mostly in low-diversity production systems. This scenario means that diversity, resilience, and sustainability are "striped out from the global food system in the name of efficiency".

Agri-food systems, which encompass production, storage, and global supply chains, are not only responsible for around a third of global CO_2 emissions but are, in turn, vulnerable to the impacts of climate change, threatening food security. For the first time, this was recognized at COP28 (2023), where 134 countries signed the landmark UEA Declaration on Sustainable Agriculture, Resilient Food Systems, and Climate Action. The message seems clear that: "*we actually have to think about the food system as a whole and not just think about agriculture*", as said by Tim Benton, director of the Environment and Society Program at Chatham House (cited by Davison[501], 2023).

However, the potential impact is less clear at regional scales. Still, climate variability and change will exacerbate food insecurity in areas vulnerable to hunger and undernutrition and on

[499] Kang, Y., Khan, S. and Ma, X. (2009) – Climate change impacts on crop yield, crop water productivity and food security. – A review. Progress in Natural Sciences, 19: 1665-1674.

[500] Tubiello, N.T., Soussana, J. F., and Howden, S.M. (2007) – Crop and pasture response to climate change. Proceeding of the National Academy of Sciences of the United States of America, 104 (50): 19686-19690.

[501] Davison, Catherine (2023) – Millets: The crop that could solve hunger and climate change. Devex, Inside Development Food Systems

those highly dependent on import markets for staple food. Likewise, it can be anticipated that food access and utilization will be affected indirectly via collateral effects on households and individual incomes. Food utilization could be impaired by loss of access to drinking water and damage to health. The evidence supports the need for considerable investment in research in adaptation and mitigation actions toward a "climate-smart food system" that is more resilient to climate change influences on food security.

When looking for Portuguese metrics on food vulnerability, we found very little information available. This is largely because the potential impacts of climate change are still uncertain and scarce and agriculture, environment and food policy generation system is an area where effective problem ownership within the public administration is particularly disperse and weak. Food vulnerability has a multidimensional character, going beyond the simple dimension of changes in the productivity of each specific culture, which has been the dominant area of studies.

Whereas these dimensions comprehensively describe food security at the individual's level, they provide little insight in structural causes of food insecurity (Vanhove[502] and Van Damme, 2011). In fact, studies exclusively centred on the analysis of climate impacts on production, although essential as a starting point, fail to get the essence of food system dynamics.

A large number of studies carried out over the last several years for various locations around the world, including those in Portugal, in identifying the challenges posed to face the vulnerabilities in order to anticipate adaptation strategies to climate change are still strongly fragmented.

The identification of the challenges facing agricultural activity and the options for its intensification necessarily needs to be complemented with solid risk analyses to face the multidimensional characteristics of climate change (scenario of rising temperatures, more intense heat waves and frequent occurrences, decreased annual precipitation, concentration of rainfall in the winter months and increased variability of precipitation in spring, prolongation of the dry summer period, increased evapotranspiration) and uncertainty and fragmentation of knowledge and information.

Moving towards a more sustainable future requires concerted action, particularly in the context of global climate change. Integrated Agricultural Systems Assessments (IAAS) are valuable tools for providing sound policy and information for decision-making.

Despite soil being the very basis of the world's food system and an essential resource for life on Earth, its increased importance because it is a fragile and non-renewable nature, at least in our lifetime, as well as the third carbon sink, it was only officially recognized at the COP27 in Sharm El-Sheikh (2022) where it was mentioned that about over half of the globe's agricultural soil was already severely degraded. This emphasis on food systems and resources at COP27 shines a powerful spotlight on soil health and food and nutrition security issues. The message was powerful: soil degradation has compromised the lives of more than three billion people and costs the global economy as much as USD 10.6 trillionyear^{-1}.

In response to these staggering figures, the CA4SH (multi-stakeholder platform launched at the UN Food Systems Summit in 2021) drafted an urgent Soil Health Resolution for governments to endorse and issue publicly during COP27 for governments and multi-stakeholders to tackle soil degradation as a matter of urgency. The resolution calls on political leaders to recognize,

---

502 Vanhove, W. & Van Damme, P. (2011) – Climate Change and Food Security – A Dynamic Perspective. Klimos Working Paper 2, KLIMOS, Leuven, 36 pp.

affirm, and support efforts to encourage farmers towards land-management practices that build healthy soil. That could be through regenerative farming techniques, including growing trees and crops that can meet the world's and national needs to feed its growing population while removing carbon from the atmosphere and sequestering in their land. Finally, it asks leaders to consider the importance of healthy soil in achieving the UN Decade on Ecosystem Restoration objectives.

The importance of soil health for food security was also unanimously recognized all over Europe, which acknowledge that its soils present a degree of degradation mainly due to human activities caused by unsustainable management practices in agriculture and forestry, contamination from industries, urbanization and infrastructures. Food choices, food chain processes, and food waste also affect soil health.

The following examples from the EU reflect the gravity of the problem (EU[503], 2020):

- 2.8 million potentially contaminated sites (only 24% inventoried) posing major health risks.
- 65-75% of agricultural soils have nutrient inputs at levels risking eutrophication of soils and water and affecting biodiversity.
- Cropland soils losing carbon at a rate of 0.5% per year; 50% of peatlands drained and losing carbon – this is contributing to the climate crisis.
- 24% of land with unsustainable water erosion rates.
- 25% of land at High or Very High risk to desertification in Southern, Central and Eastern Europe.
- The costs associated with soil degradation exceed 50 billion € per year.

Recognition of the magnitude of soil health related problems and the urgency to resolve them requires "*transformational changes in policy, management practices and a re-design of production systems and land management*" (EU, 2020). Research and innovation must urgently address all these dimensions. There is knowledge within individual disciplines but hardly any integrated knowledge about soil health that combines that knowledge and the agriculture sector's needs.

To bridge this gap at the EU level, Horizon Europe's next Soil Mission aims, with a strong dose of optimism, to ensure that three-quarters of European soils are healthy by 2030, slowing climate change and safeguarding food supplies. Despite the critical importance of soil health and unlike reporting on water quality and biodiversity, which are mandatory in the EU, there is no requirement for reporting on soil health, as, in 2007, a proposed soil directive was not approved. So, up to now, pan European data on soil status was not available since there has been no EU policy or legislation for soils. As a result, what is also true for Portugal, the soil is "a forgotten natural asset".

Concerning Portuguese agricultural research information, the critical dimension of soil health is still not available, and there is no data on how many soils will cease to be productive or able to adequately regulate the water and carbon cycles due to this degradation. It is known that around

---

[503] EU (2020) – Caring for soil is caring for life. Mission Board for soil health and food. European Commission. Directorate-General for Research and Innovation and Directorate-General for Agriculture and Rural Development, Brussels, 82 pp.

60% have little organic matter and that around 20 tons/ha/year of soil are lost (Pinto Correia[504], 2023). Despite Portugal's participation in the EU Soil Health and Food Mission, the issue of soils and the consequent policies and instruments needed to meet the targets assumed for 2030 were utterly neglected in the Portuguese Strategic Plan for Policy Agricultural Policy 2023-2027 presented in Brussels.

In addition to the policy measures to fulfil internationally assumed commitments by Portugal, agricultural research institutions are called upon to rethink their strategic research and innovation priorities, which must be conceived to contemplate systemic, interdisciplinary approaches of knowledge co-creation, regional differentiation, and social support, under penalty of its activity being ineffective in terms of responding to the challenges of climate change and food security and fulfilling the Nature Restoration Law (a crucially element of the Green Deal), which defines legally binding targets for the EU member states (European Commission[505], 2023). There is still a strong science-policy gap that hinders decision-making, and action based on the best available knowledge (Báldi[506] et al., 2023).

8.1 – A short list of adaptation and mitigation options: meeting the challenges

Prevention of soil degradation and mitigation of desertification risks is a crucial issue for the sustainable management of agriculture, forests, and, generally, natural environments in Portugal and the dry Mediterranean region. Natural systems' vulnerability to a changing climate is a function of their likelihood, sensitivity, and capacity to adapt to the change being experienced.

Thus, responding to the challenges of guaranteeing food security, supporting agricultural and forestry development, and meeting the need to adapt and mitigate agricultural and forestry ecosystems to climate change will require a broad commitment from the Portuguese community. Beyond that, it is needed more substantial financial transfers to the farm sector than that have been carried out so far and concerted national and multilateral policy actions involving the convergence of adaptation, climate change mitigation and trade requiring a further institutional reorganization avoiding policies dispersed by several decision-making centres conducting to contradictory policies between them.

For the sake of precision of the nomenclature of intervention measures one should differentiate the understanding between mitigation and adaptation as follows (IPCC[507], 2007): "*Mitigation is an anthropogenic intervention to reduce de sources or enhance sinks of GHG while adaptation is an adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*".

---

504 Pinto-Correia, T (2023) – Caring for the soil is caring for the life. Mission Board for Soil Health and Food. #MissionSoil #EUMissions #HorizonEU. EU Commission, 12 pp. [*http://ec.europa.eu/mission-soil*]

505 EU Comission (2023) - [*https://www.europarl.europa.eu/news/en/press-room/20230707IPR02433/ nature-restoration-law-meps-adopt-position-for-negotiations-with-council*]

506 Báldi, András., Öllerer, K., Wijkman, A. Bunori, G., Máté, A. and Batáry, P. (2023) – Roadmap for transformative agriculture: From research through policy towards a liveable future in Europe. Advances in Ecological Research, 68: 129-152

507 IPCC (2007) – Climate Change 2007: Working Group III: Mitigation of Climate Change. [https://ipcc.ch/pubçications_and_data/ar4/wg3/en/ch2s2-5-2.html]

Mitigation of climate change is the measures implemented to attack the root causes of increasing GHG emissions in the atmosphere (reduce the sources) or increasing "sinks" of GHGs. Global proactive mitigation policies can change the direction towards a sustainable transition (Grim[508] et al., 2010), preventing an increasing number of disasters.

Adaptation refers to efforts to reduce vulnerability and increase of resilience of natural and human systems to impacts of climate change. It encompasses precautionary learning, and resilience in regions and communities exposed to environmental change allowing the development strategies and capabilities needed to protect people from the consequences of future climate events effectively, to implement green agriculture-adapted processes and restoration of ecosystem services that will not only improve water retention and supply and air quality but also reduce adverse risks of intensive climate events. The concept includes changes in processes, practices and ecological, economic and social systems (Wiegman[509], 2010). These broad definitions demonstrate that adaptation incorporates both environmental and social-economic policy domains.

Mitigation requires effective cooperation among global stakeholders, and such efforts are, therefore, most relevant at a larger forest scale. In contrast, adaptation strategies may be relevant at all scales, although Pittock[510](2009) considers them an essential local challenge.

Table 29 shows the differences in time scale and scope of each one of the interventions.

Table 29 – Mitigation and adaptation strategies

	Mitigation	Adaptation
Effects/Benefits	Global	Regional/Local
Timeframe	Decades/Centuries	Days/Months/Years
Implementers	UN/National Governments	Individuals/Local and State Governments
Effectiveness	Measurable	Mensurable

As agriculture activities are themselves a significant driver of climate change, decreasing its negative impact on food production, mitigation has become a focal point for reduction strategies. The mitigation strategies used to reduce the amount of GHG range from improving crop and livestock management to changes in farming techniques, whose degree of effectiveness and efficiency are depicted in Fig. 48.

The uncertainty about GHG emission estimates from the agricultural sector is one of the impediments to mitigation activities. Limited information to establish terrestrial carbon baselines at the national level and the high cost of measuring, reporting and verifying agricultural GHG

[508] Grim, J., Rotmans, J. and Schot, J. (2010) – Transitions to Sustainable Development, New Directions in the Study of Long Ter Transformative Change. London: Routeledge.

[509] Wiegman et al. (2010) - "Climate adaptation." In: Encyclopedia of Earth. Eds. Cutler J. Cleveland (Washington, D.C.: Environmental Information Coalition, National Council for Science and the Environment). [First published in the Encyclopedia of Earth, 8 December 2009; Last revised 5 January 2010.

[510] Pittock, A.B. (2009) – Climate Change. The Science, Impacts and Solutions, 2nd ed. eBook, CSIRO Publishing

emission reductions, have plagued international efforts to create mechanisms that would reward agricultural GHG mitigation activities (UNFCC[511], 2010).

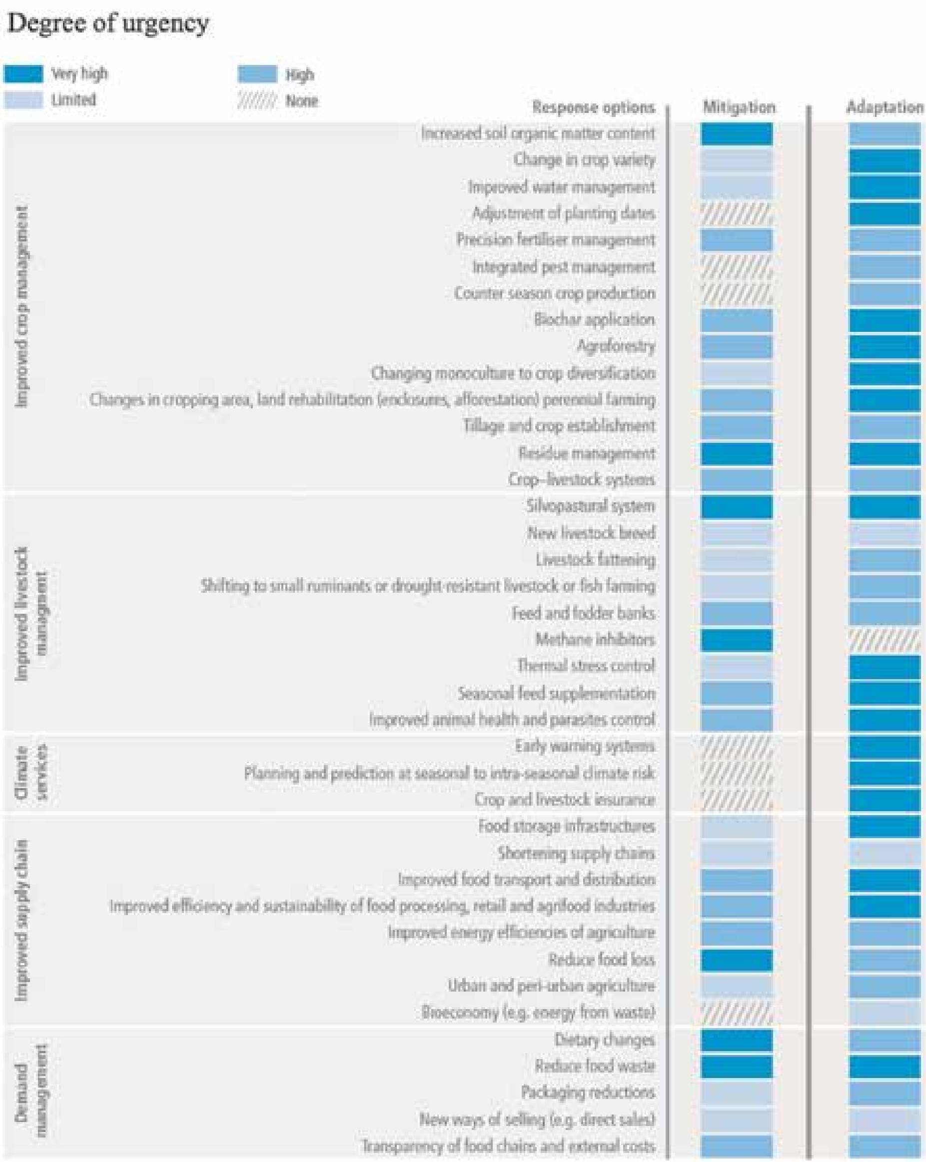


Fig. 48 – Food systems response options
Source: IPCC Special Report on Climate Change and Land (2020)

While these strategies are shown to be successful in curbing GHG emissions in the long term, mitigation alone is not enough because the effects of mitigation measures are generally long-term

---

[511]). UNFCCC (2010) – Report of the Ad hoc Working Group on Long-term Cooperative Action under the Convention in its eight session, FCCC/AWGLCA/2009/17, 44 pp.

and expensive. The urgency of reducing emissions from the agricultural sector calls for governments to implement simultaneous adaptation policies to reduce the risks of episodes of food insufficiency and consequent crises in the social and health domains. The Paris Agreement is equally clear regarding the forestry sector, encouraging the development of approaches that combine mitigating measures with adaptive measures to achieve integrated and durable forest management.

Adaptation frameworks generally distinguish between those that are incremental or systemic, often associating them to autonomous or planned adaptation, respectively. However, even incremental, or autonomous adaptation needs to be facilitated, supported, and enabled, which requires appropriate means, institutions, and policies. Incremental changes could require specific planning.

Depending on the types of agroecosystems, incremental changes can be introduced more or less easily, at shorter or longer time scales, and impacts of those changes can take more or less time to be effective.

From the list in Figure 48, and without excluding any of the options to be implemented in each situation and exploration unit, it seems to us that generically the priority options for the Portuguese situation will be the following: i) increase in organic matter content on soil; ii) improving water management; iii) counter-season agricultural production; iv) application of biochar; v) improvement of agricultural systems; vi) soil preparation (e.g. non tilling) and crop establishment; vii) bioeconomy (e.g. energy from waste); viii) transparency of food chains and external costs.

Although the need for effective adaptation options in agriculture is recognized, the sector also has considerable potential for other short-term adaptation options that are far from being exhausted with the list presented above (Smith[512] et al., 2008; Schlamadinger[513] et al., 2007).

Changing the use and management of agricultural land to support mitigation objectives or adaptation plans is likely to have other environmental and climatic effects, including those on hydrology, which may be beneficial or detrimental to the original purpose. Changing water management practices to adapt to climate change could also affect the effectiveness of agricultural mitigation and adaptation options. For instance, increasing agro-ecosystem carbon storage and improved field boundary management could create buffer zones to prevent nutrient losses to surface water and reduce surface runoff and erosion. Similarly, planting biofuel crops on arable lands could be a significant carbon mitigation option. Still, while they could also minimise nitrate losses (Börjesson[514] and Berndes, 2006), they could have opposite effects, such as intensified water use and increased nutrient losses (IPCC[515], 2008) or increased competition for agriculture land could result if poorly located, designed, and managed. Actions in these areas include forest conservation and the promotion of non-extractive livelihoods. Because both sectors are

---

[512] Smith P., Martino D., Cai Z., Gwary D., Janzen, H.H., Kumar, P., McCarl, B., Ogle, S., O'Mara, F. et al. (2008) - Policy and technological constraints to implementation of greenhouse gas mitigation options in agriculture. *Agric. Ecosys. Environ.* 2008:118: 6-28.

[513] Schlamadinger B, Bird N, Brown S, Canadell P, Ciccarese L, Clabbers B, Dutschke R, Fiedler M, Fischlin A, Forner C, Freibauer A, Hoehne N, Johns T, Kirschbaum M, Labat A, Marland G, et al. (2007) - Options for including LULUCF activities in a post-2012 international climate agreement Part I—Synopsis of LULUCF under the Kyoto Protocol and Marrakech Accords and criteria for assessing a future agreement. *Environ Sci Policy* 10: 271–82.

[514] Börjesson, P., Berndes, G. (2006) - The prospects for willow plantations for wastewater treatment in Sweden. *Biomass Bioenergy* 30: 428–38.

[515] IPCC (Intergovernmental Panel on Climate Change) (2008) - Climate Change and Water. Technical Paper of the Intergovernmental Panel on Climate Change, IPCC Secretariat, Geneva; 2008. p. 210.

interconnected, the Paris Agreement encouraged the development of approaches that jointly address mitigation and adaptation for the integrated sustainable management of forests. It must acknowledge the strong linkages between land use, land-use change, and forestry.

Cross-sectoral adaptation measures may include climate-smart agriculture, the restoration of degraded lands through reforestation and land restoration, watershed management and on-farm soil and water conservation measures, and the sustainable use of wood fuels.

Forest-related measures proposed in national adaptation plans must include providing forest employment, maintaining access to forest land and resources, and strengthening participatory community-based governance to increase the resilience of forest-dependent people. In Table 30, we list some forest-related mitigation and adaptation options.

Table 30 - Possible Forest related responses to climate change

Mitigation options	Adaptation options
• Carbon sequestration through increases in forests and trees and forest carbon stock I. Afforestation, reforestation, and forest restauration II. Increase of tree cover in farming systems (agroforestry) III. Enhance of carbon stocks and sequestration capacity through silviculture practices • Forest carbon stock conservation through reduction of deforestation and forest degradation I. Addressing drivers of deforestation II. Promotion of sustainable forest and land management III. Effective conservation of forest protected areas IV. Integrated fire management V. Management of forest health and vitality • Promoting and enlarging wood application	• Reducing vulnerability and strengthening adaptative capacity of trees and forest especially in fragile forest ecosystems I. Management of forest biodiversity, including through supporting adaptation of species and more suitable provenances II. Maintaining forest health and vitality to reduce vulnerability III. Avoiding landscape fragmentation and enhance biodiversity corridors • Maintaining forest health and vitality to reduce vulnerability • Improving fire suppression and control • Reducing vulnerability and strengthening adaptative capacity of forest dependent communities I. Reinforcing local coping mechanisms II. Strengthening capacities of community-base organizations for improved governance III. Diversifying forest related products and employment opportunities and livelihoods IV. Practicing adaptative land use planning and management

Adapt. from: FAO[516] (2018)

When choosing an alternative, one must be conscious that there are no silver bullets because of the site-specificity of each agriculture system and ecological unit where each agriculture is

[516] FAO (2018) – Climate change for forest policymakers. An approach for integrating climate change into national forest policy in support of sustainable forest management, Rome. FAO Forestry Paper 181, 73 pp

exerted. For example, there are many uncertainties regarding climate impacts on water and agriculture, including the complex interactions between the two sectors and climate change.

In Portugal, policies related to forests, agriculture, and climate change fall under the responsibility of different government sectors and involve different groups of stakeholders and experts. The exchange of information across very compartmentalized administrative and sectoral boundaries on forestry and climate change issues is often limited, and the principles of good governance are not always applied in the best possible way. Furthermore, the forestry sector's potential to support climate change mitigation and adaptation at the national level is not fully appreciated.

The accumulation of carbon stock is mainly performed by forest and sustainable cropping and grazing systems. Soil organic matter (SOM) is composed of approximately 45% of soil organic carbon (SOC). Increasing SOM (and thus SOC) in agricultural soils to meet mitigation objectives will also improve their water-holding capacity, potentially reducing crop system water losses and the need for irrigation. SOM content can also affect soil colour and albedo for limited geographic areas and soils with similar morphologic properties (Schulze[517] et al., 1993). Therefore, changes in soil moisture and SOM status could also affect the local radiative balance and potentially cause additional local cooling or warming, impacting evaporation rates from the soil.

On the other hand, since SOC losses could increase with rising temperatures, the changing climate could alter the potential for mitigation in the agriculture sector (Fallon[518] and Betts, 2009). Climate-induced reductions in SOC content could also alter the effectiveness of adaptation options in agriculture by changing soil fertility, nutrient status, and water-holding capacity. The projected trend towards hotter and drier summers and increased droughts in the Mediterranean leads to increased crop irrigation needs, affecting water availability for other sectors, as already mentioned for the Alentejo and Algarve, but also alters agricultural SOC storage since moisture is a strong driver of SOC changes. For this reason, increasing irrigation of croplands would also likely reduce SOC storage, assuming net primary productivity (NPP) remained unchanged. However, there is a consensus that irrigation leads to an overall increase in SOC (Lal[519], 2004) when NPP changes are considered. Deforestation and the reduction in tree density in cork oak forests, with the changes it induces in albedo, negatively impact the already low levels of soil organic matter in Alentejo soils.

These interactions are numerous, complex, non-linear, and often poorly understood, requiring research institutions to design and implement projects that explicitly aim to define adaptation and mitigation options adapted to the different ecological regions of the country and their different socioeconomic contexts.

Adaptation options must also be considered to sustainably increase production to address growing demand driven by population growth, changing diets, and potential mitigation co-benefits. There is a need to assess potential trade-offs carefully, or synergies, between increased efficiency in using resources on the one side and resilience on the other. Despite the uncertainties in quantifying climate change impacts in agriculture and forestry, there is a consensus that changing course is critical; "business as usual" is no longer an option. If food and agricultural

---

[517] Schulze, D.G., Nagel, J.L., Van Scoyoc, G.E., Henderson, T.L., Baumgardner, M.F. (1993) - Significance of organic matter in determining soil colors, pg. 71 - 90. In: Bigham JM, Ciolkosz EJ, (eds). *Soil Color*, vol 31. Madison, WI: SSSA Special Publication; 1993.

[518] Falloon, Pete, Betts, R. (2010) - Climate impacts on European agriculture and water management in the context of adaptation and mitigation—The importance of an integrated approach. *Science of the Total Environment*, 408: 5667–5687.

[519] Lal, R. (2004) - Soil carbon sequestration impacts on global climate change and food security. *Science* 304:1623-7.

systems remain on their current path, the evidence points to a future characterised by persistent food insecurity and unsustainable economic agriculture or forestry. Many countries and Portugal are already committed to increasing the sustainability of their food and agriculture systems. However, fully meeting Sustainable Development Goals (SDGs) targets, as envisaged by the 2030 Agenda for Sustainable Development, will require additional efforts to address growing inequalities and gender imbalances, sustain peace, reduce GHG emissions, avoid resource-depleting farming and forestry systems, manage the demand for resource-intensive animal food and feed products, and reduce food loss and waste, among other challenges.

Although a full assessment of the GHG emissions due to Portuguese agriculture is still in the making, it is clear that industrialized agriculture is a significant source of GHG emissions. As agriculture represents an important income-earning activity, mitigation actions must be designed to help ensure food security, alleviate poverty and answer to international commitments to reduce GHG emissions. Achieving this goal means that institutions should initiate a fundamental "rethink" on how agriculture is practised. Finding ways to reduce reliance on chemicals and synthetic fertilizers and creating incentives to promote the use of renewable energy throughout the modern agricultural systems and suitable agriculture options, leaving lower carbon emissions print, is of the utmost urgency and requires concerted policy action. The concern over climate change and the need to shift to more sustainable systems has raised interest in many long-standing practices, including conservation and organic agriculture and greater reliance on renewable energy for domestic use in rural households.

The national approaches we have seen in Portugal to resolve food insecurity and the resulting hunger problems are mostly concentrated in seeking to reduce the lack of access to food through food aid. Critically, food policies at all levels rarely address the mechanisms of social control related to the food system and the scaling up of social protection systems. Productivity and problems involved with the organization of food chain markets or wastes are hardly the subject of a broad discussion on aspects of food sovereignty to adopt dynamic equilibrium on their approach to addressing food insecurity impact of climate change, which needs urgent attention. In recent years, food dependence has worsened in Portugal. In fact, according to data from the Alliance Against Hunger and Malnutrition ACFMN[520] in 2022, they identified 4500 institutions that provide food aid (Food Bank, Caritas, other IPSS), which is 500 more than those registered in 2019.

Regarding to Portugal we think worth transcription of the references produced in the Dialogue Focus & Outcomes[521] (2021): "*Since 2015 we have known that the food footprint of Portugal's population is well above the average for Mediterranean countries, distancing itself far from the consumption patterns established by the Mediterranean diet. Associated with this unsustainability we also know that poor nutrition is the leading cause of premature mortality and multiple chronic diseases among Portugal's population.*"

Bearing in mind that Portugal imports, on average, about 75% of the corn it needs, more than 90% of the wheat to make bread and pasta, 47 % of rice, and 31 % of potatoes for its supply, we have the perfect picture of the vulnerability of the Portuguese food system, which is highly dependent on international transport whose prices have been rising in the last three years and especially in 2021 which adds up to the geopolitical vulnerability of the leading supplier

520 ACFMN (2022) – Mapeamento da Distribuição da Ajuda Alimentar em Portugal. Aliança Contra a Fome e a Má-nutrição. [www.acfmnportugal.pt/os-projectos/mapeamento-da-distribuição-da-ajuda-alimentar-em-portugal]

521 Food Systems Summit 2021, July Dialogues. [https://summitdialogues.org/dialog/23623/official-feedback-23623-en-pdf?t=1626995789]

countries. Looking at the changes that have taken place in the panorama of Portuguese agriculture, the prospects for improving the national food system or reducing food vulnerability do not seem encouraging. The worsening trend in the international cereal supply scenario, together with the pressure resulting from the reduction in cereal production in 2021 compared to 2020 (not counting the increased risks resulting from the current political-military instability in Europe) and the increase in consumption, is added the fact that the cereal sector in Portugal is losing every bit of money and more land areas are substituted for other more short term profitable crops especially in the "montado", to give way to super-intensive olive oil plantations, almond groves and more recently to avocado. These risks worsened in 2023 as data from the 2023 cereal agricultural campaign show that the cereal harvest - excluding corn - is facing the worst results ever in its production since there are records, around 100 years ago - which is below 5% of national needs. The continuation of the war and the drop in output means that Portugal will have to deal with the constraints of searching for new, geographically more distant alternatives to Ukrainian cereals. As if that weren't enough, *Silopor*, the company through which practically all grains imported by sea pass, has been in liquidation for years, with a management that does not allow it to modernize and expand its storage capacity.

This situation allows us to say that Portugal is in the “eye of the storm” of the current global market for cereals for human and animal food. This dependence means that Portugal ranks 9th in imported deforestation caused by international trade, meaning it plays a crucial role in minimizing this problem.

Such large-scale changes we assist mainly in the Alentejo, seen for some as examples of modernity in Portuguese agriculture, should be considered with some caution and be subject to careful analysis not only from the point of view of food security but also regarding the sustainability of this type of development; and also, not only in terms of the fertility of the Alentejo soils but also in terms of the environmental impact they cause. Such profound change we assist in Montado/Dehesa seems to be at the very heart of a profound dilemma of a predominant paradigm of economic development in agriculture (made at the expense of the high increase in inputs in fertilisers, pesticides, herbicides, heavy mechanisation or heavy imported cheap labour and heavy reliance on irrigation). Without changes in land use policies and the right incentives to value ecosystem assets, the economic growth paradigm will continue to drive demand for olive oil, almonds, and avocados, putting long-term pressure on oak forests in the south and losing the mitigation effect of forests in the quest for carbon neutrality.

Despite the negative impacts of the interventions seen in significant areas of Alentejo soil (increase in GHG emissions, soil degradation and loss of biodiversity, increased risk of natural disasters due to the increased vulnerability to ecological changes it causes), containment and recovery plans are timid and spatially limited. To a large extent, this situation results from the ambiguity that was established due to the agricultural development model applied. In environmental terms, the restrictions imposed by soil degradation and water availability do not seem to confer socioeconomic and ecological sustainability on a farming system based on the intensification of monocultures in a vulnerable area prone to an increasing frequency of droughts.

To this regard, quite recently, geographer Teresa Pinto Correia (2023), who represents Portugal at the EU Soil Health and Food Mission, stated in a manifesto calling for urgent action to ensure soil health that "*especially when we have super-intensive agriculture managed by investment funds, as is the case in the Alentejo, based on a business model that has access to cheap land and water, extracts the product business, degrades the soil and leaves*".

Short-term or opportunistic strategies will be highly detrimental to the sustainability of Portuguese soils, particularly the most susceptible ones. Quite recently, FAO[522] (2018) recalled that the future of agricultural production growth would be constrained by increased scarcity, diminished quality of land and water resources, and insufficient investment in sustainable agriculture. Unaddressed climate change will increasingly affect yields and rural livelihoods while agriculture will keep emitting GHGs.

In short, future Portuguese agricultural production, in the face of predictable climate change, will depend not only on containing the downward trend in productivity, which is shown to have a significant probability of happening, but also on the ability to generate anticipated forecasts that will be determined, not so much by climate change, but mainly by socioeconomic factors, such as the interaction of land and labour in response to population dynamics, technological development, availability of capital as well as enabling and supportive public policies.

Paradoxically, when we talk about food vulnerability and dependence on imports in a country where 20.1% of the population lives at risk of poverty or social exclusion, with 5.3% in a situation of severe material and social deprivation (ONLCP[523], 2023), and 4.1% are in a situation of moderate and/or severe food insecurity (INE[524], 2023), we find that at least more than 1 million tons of food are wasted annually (ACFMN[525], 2020). Let us not forget that food waste is an ethical, social, and economic problem and a severe environmental problem as it increases the country's ecological footprint.

Future Portuguese agriculture production faces several challenges that need to be understood in scope and implications: 1) growing and increasingly wealthier population are projected to demand more and different compositions of food commodities, namely meat, known as having a high environmental footprint; 2) climate change impacts will require adaptation, for which there is little integrated information and research is uncoordinated and underfinanced and 3) the environmental impact of agricultural production needs to be reduced, including pollution, water consumption, land consumption and greenhouse gas emission.

The evidence base for climate change impacts on national or regional food security is heavily skewed towards food availability, with severe gaps in the broader aspects of food security. These are, however, much more complex than determining the physical quantities of food that are produced since they miss the other components: products stored, processed, distributed, exchanged and industrial inputs (fertilizers, herbicides, and pesticides).

Here, the determining factor is the purchasing power of the various population strata. Thus, food prices are an essential indicator of food security. Food prices, in theory, are determined by the balance between supply and demand. Still, the agri-food system is quite complex because many factors play a role in the price formation of food products and the dependence of the internal market on imports. Let's not forget that the first decade of the 21st century has seen several harbingers of a troubled future for global food security. The food price spike for food commodities of 2008-2009 was due to a combination of adverse factors from the oil price spike to the growing demand for food from emerging economies leading to the decline of food

---

522 FAO (2018) - *The future of food and agriculture – Alternative pathways to 2050*. Rome. 224 pp.

523 ONLCP (2023) – Observatório Nacional de Luta contra a Pobreza. Relatório [https://on.eapn.pt/pobreza-em-numeros/pobreza-ou-exclusao-social/taxa-de-risco-de-pobreza-ou-exclusao-social]

524 INE (2023) – Objetivos de Desenvolvimento Sustentável. Indicadores para Portugal 2015-2022. 123 pp

525 ACFMN (2020) – Desperdício Alimentar, o seu Impacto Ambiental e a Ajuda Alimentar, Observatório Nacional de Luta contra a [www.acfmnportugal/direito-a-alimentacao-e-segurança-alimentar/desperdício-alimentar]

commodity stocks, commodity speculation and macro-economic factors such as weak US dollar and low-interest rate (Sarris[526], 2009) resulting in food riots in several countries, including some in the Mediterranean, awaking the world's leaders to the re-emergence of this threat to human well-being and social harmony.

Furthermore, one must remember that the tight supply available on the food commodity market for certain strategic products, like cereals, increases the risk of disruptions in procurement and shortfalls in food availability in a country with high cereals dependency ratios (World Bank[527], 2012). A further point which should be emphasised is the similarity, often misleading, of the concept of food security and self-sufficiency; indeed, food trade deficits may be an acceptable way of guaranteeing the availability of food supplies, but only in the conditions that a deficit-prone country as Portugal can generate enough foreign currency to pay for its imports. In practice, it means being able to keep a relatively low ratio of food imports over total exports to pay for their food imports. The ongoing deficit in the agricultural sector's trade balance in Portugal (Fig. AII.1, pp 272) and the recurring negative general trade balance mean relatively high vulnerability of the national food sector due to its external dependence and sensitivity to high price shocks, which tends to aggravate nowadays with high levels of inflation and exacerbation of the instability signals we are assisting in the world.

The evolution of food price indices is not reassuring, and the rise in recent years can hardly be attributable to climate change. In fact, the FAO global food price index surpassed the threshold of 120 points in April 2021, reaching 127.8 points in May (a record since the beginning of the series in 2003) and closing in July at 123 points. The 4.8% jump in May was the biggest since October 2010, representing a 39.7% rise in one year and encompassing all food categories.

Nelson[528] et al. (2010) mentioned that the seeds for these challenges, both for good and ill, were planted along with the Green Revolution crops in the mid-1960s. Dramatic increases in food production and land productivity led to complacency about the remaining challenges ahead, resulting in reduced public sector investments in agricultural research directed to enhance productivity. Population numbers continue rising towards an anticipated 9 billion by 2050 (level already reached in 2023), while higher incomes in hitherto emerging countries will lead to increased demand, putting additional pressures on sustainable food production. To those already daunting challenges, climate change adds further pressure. The picture seems clear: farmers everywhere must adapt to climate change. The changes might ultimately benefit a few, but for many, our revision points to significant challenges to productivity and more difficulties in managing risks. The agricultural system, as a whole, will have trouble supplying adequate quantities of food to maintain constant accurate prices. This adaptation requires early action on adaptation, mitigation, and resource protection, which is also disputed by other sectors with greater claiming power over the political forces.

The challenges extend further to the national government to provide the supporting policy and environmental infrastructure and to the global trading regime to ensure that changes in comparative advantage translate into unimpeded trade flows to balance world supply and demand.

---

[526] Sarris, A. (2009) – Evolving Structure of World Agricultural Trade and Requirements for New Trade Rules. Paper presented at the Expert Meeting on "How to Feed the World in 2050. June 24-26. FAO, Rome, 29 pp.

[527] World Bank (2012) – Connecting to compete 2012. Trade logistic in the global economy. Washington DC.

[528] Nelson, G.C., Rosegrant, M.W., Palazzo, A., Gray, I., Ingersoll, Christina et. al. (2010) - Food Security, Farming, and Climate Change to 2050: Scenarios, Results, Policy Options. International Food Policy Research Institute. 131 pp.

The above factors are expected to persist into the future, adding to predictable declines in yields due to increased climate change, hence volatility in food commodity prices, although their particular importance remains uncertain. After 2050, different SRES A2 models predict an increase in real cereal prices of 21 to 23% and a global agricultural real prices increase of 7 to 8% in 2080. Despite the vast uncertainties inherent to the models used on the size of the values and the certainty that climate change will negatively impact Portugal, these are real alerts to the urgency in the design and implementation of mitigation and adaptation measures in agriculture and forest ecosystems.

Because of being highly dependent on water, the agricultural sector has to adopt measures to adapt to climate change. Some of the solutions that have been indicated pass by enhancing the water retention capacity of farming soils (biochar applications may have high potential), reducing the flow of rainwater during the winter, promoting infiltration, choosing better-adapted varieties (with thermal and vernalization needs more suitable and more resistant to thermal and water stress), increasing management efficiency of water resources and water application of watering and shortening distribution circuits as much as possible to reduce transport costs and food waste.

There is no doubt that Portugal has to adopt active mitigation and adaptation actions designed to reduce vulnerabilities and enhance the food system's resilience to climate change. In some areas, expanded climate envelopes are bound to alter agroecological zones, with different agriculture opportunities. There are many options for adapting the food system requiring both technological (e.g. recovering and improving orphan crops, new cultivars from breeding or imported from bioclimatic homologous zones) and non-technological (e.g. markets, land management, dietary changes) solutions, all falling under the umbrella of sustainable intensification (Jörissen[529] et al., 2014). High engineering technological approaches mainly focus on increasing the efficiency of external inputs (fertilizers and pesticides) and scientific advances in precision farming, plant breeding and genetic engineering. Agroecological approaches are targeted at the reduction of external inputs (synthetic fertilizers and pesticides have a high climate footprint) based on a better understanding of ecological interrelationships and improving farm practices such as no-tillage, cover cropping, crop rotation, intercropping associated with a case by case with agroforestry, nutrient management, and water conservation strategies.

Given the site-specific nature of agriculture and climate change impacts on food system components and wide variation in agroecosystem types and management and of the socio-economic conditions, it is widely understood that adaptation strategies must be linked to environmental and cultural contexts at the regional and local levels. Developing systemic resilience that integrates climate drivers with social and economic drivers will be essential to reducing the impact on food security but simultaneously is a significant challenge for agriculture and forest research institutions.

A particular challenge involves interactions between land-based non-food system mitigation, such as negative emissions technologies, and food security. As described by the IPCC Special Report (2020), options for the food system have synergies and trade-offs between climate change mitigation and adaptation, as depicted in Fig. 48, where it is clear that many response options offer significant potential for both mitigation and adaptation.

Faced with the need to tackle the increase of meteorological phenomena/extreme weather, it is relevant to deepen current knowledge and strengthen existing capabilities by better

[529] Jörissen, Juliane, Meyer, R., Priefer, C., Bräutigam, Klaus-Rainer (2014) – Future Food Systems: Challenges and Perspectives, Technikfolgenabschätzung – Theorie und Praxis 23: 4-7

surveillance and climate monitoring as well as improved and timely forecast meteorological data. This enhanced information will be increasingly important and relevant in anticipation of risk management impacts. Therefore, increasing the weather forecast's time horizon and spatial resolution is crucial for improving predictive ability and reducing uncertainty in forecasting models.

Over the most recent years, extreme climate events, biodiversity losses, and new a more severe food crises have come into sharper focus. Events like conflict in Ukraine and drought in East Africa have reminded us of our vulnerability and interconnectivity and the urgent need to work together to broadly transform food systems, energy sectors, and relationships with nature.

Risk reduction, in the impossibility of controlling the atmospheric component, will only be effective with timely adaptation, vulnerability reduction, support advisory services, effective decision support systems, and a new culture for climate risk.

Foreseeable climate trends and the increased frequency of climate anomalies in Portugal reinforce the evidence of a future with less freshwater availability, reduced land productivity, and decreased food security. So, again, public institutions and those responsible for the water resources policies and agricultural research need to increase their capacity to implement mitigation and adaptation measures on water irrigation and new water resources planning and land management policies, including land use and cover as well as changes in farming technology along with all production change. These measures require urgent attention to strengthen food and nutrition security.

To support these actions, we highlight the need to strengthen coordination, assessments, monitoring, and surveillance systems. Building resilience and contributing to global food and nutrition security in the longer term requires more effective policy responses to climate and environmental change and enhanced adaptation to impacts. To maximize the synergies in Portugal's development and design effective strategies to reduce negative trade-offs implicit in various land management practices affecting agriculture, forestry, and livestock production, it is mandatory to integrate land use competing options, food security, adaptation, and development into climate change strategy mitigation.

Additional critical outcomes are needed: 1) agriculture research and extension enhanced to allow sustainable, productive output; 2) the urgent need to stimulate synergies between science and the agricultural sector as a way to improve and develop new products and decision support applications; 3) smallholder farmer-led food availability sustainable growth; 4) widespread public awareness and participation towards responsible water-saving practices; 5) social protection systems to be drawn and expanded to cope with weird climate vagaries; 6) safeguards and better regulation to avoid significant changes in land cover with agricultural capacity; 7) trade and tax policies to be adjusted; 8) knowledge of competing land-use impacts and 9) macroeconomic implications to be managed along with the need to a coherent financial package.

Finding new and adequate solutions to the challenges facing agriculture, rural development, and food systems in a tight time frame requires a solid and efficient research and innovation capacity. New knowledge must be generated, and all available knowledge must be put to good use, meaning there is an urgent need to reform the agrarian research structure and planning. The urgency to put efficient mitigation, adaptation, extension actions, and outreach programmes into effect means that Portugal and the agriculture sector can no longer afford uncoordinated activities. The efficiency of research and knowledge mobilisation is the essence. In the context of the evidence that suggests the need for integrated interventions, it is urgent not to forget the role of educational institutions at all levels in developing a culture of stewardship, which is the first step towards transforming our economy and society to support biodiversity rather than extinguish it. We need to start seeing land and nature as a community we belong to rather than commodities to exploit. This is stewardship in simple terms.

Although coordination of research and innovation activities within the EU has improved the progress during the FP7 programmatic period with the development of tools like Era-Nets, JPIs, ETP, and EIT, its effects are still fragile. Concerning particularly to forests, new and emerging climate change funds could provide instrumental support to countries' adaptation and mitigation actions specifically and to their efforts to achieve sustainable forest management more broadly.

However, coordination with the agricultural research and innovation systems among several Portuguese institutions and Mediterranean countries remains weak. The opening of topics and funding within H2020 to multinational teams (including the Mediterranean countries in the south) is a significant evolution. Still, it does not suffice for effective coordination of research policy programming. The magnitude and urgency to address risks faced by agriculture and food in Portugal and the Mediterranean are incompatible with the available funds, the dispersion of efforts, and the lack of coherent policy.

These actions listed are neither exhaustive nor exclusive. They are intended to guide assessments and strategies to be developed at the country level.

Finally, we recognise at the forefront that any effective environmental policy for Portugal needs a more effective and integrated political response to climate and ecological changes in the agricultural system. Achieving this will require strengthening mitigation of drivers of environmental change, such as greenhouse gas emissions, improved adaptation to impacts, and coherent and consistent land-use planning within each landscape unit.

8.1.1 - Forest contribution to food security and carbon sequestration

The speed and intensity of disasters induced by climate change is outpacing the population's capacity to cope with food losses. Ecosystem resources are already stressed by overexploitation, pollution, habitat destruction, degradation and fragmentation. As estimated, about 1.5 billion people depend on degraded land (UNCCD, 2014); 1.6 billion people live in areas with water scarcity (World Bank, 2014); 2.6 billion people worldwide are dependent on wood fuel and charcoal for cooking and heating, mainly in developing countries (FAO, 2015); and about 795 million people are undernourished globally (FAO[530], IFAD, UNICEF, WFP, WHO, 2023). How can we address these existing challenges and feed 9-10 billion people by 2050?

Maintain and increasing forest land resources is an opportunity to safeguard our natural capital and support food and nutrition security. Empirical information has shown it promotes the sustainable use of natural resources, enhances the resilience of ecosystems, protects and restores the landscape – not only the forests, but also the agriculture, agroforestry, mangroves, and more, that sustain the lives of urban and rural communities.

[530] FAO, IFAD, UNICEF, WFP, WHO (2023) – *The State of Food Security and Nutrition in the World. Urbanization, agrifood systems, transformation and healthy diets across the rural-urban continuum*. FAO, Rome. 316 pp

Forests were, until recently, rarely considered in food security discussions other than being perceived mainly as a reserve for further agricultural expansion (Bahar[531], et al., 2020). However, new global estimates mention that one-third of the human population depends on forest goods and services and that forests play a major role in providing food to local communities (non-timber forest products, mushrooms, fodder, fruits, berries, etc.) and diversify daily diets directly or indirectly through improving productivity, hunting, diversifying tree-cropland-livestock systems, and grazing in forests, the global potential to enhance food security is moderate for forest management and minor for reduced deforestation (FAO[532] et al., 2013; Rowland[533] et al., 2017). Yet, of the estimated net forest loss of about 4.7 million hectares per year, 80% results from habitat loss to agriculture. Managed natural forests, shifting cultivation and agroforestry systems are demonstrated to be crucial to food security and nutrition for hundreds of millions of people in rural landscapes worldwide (Sunderland[534] et al., 2013; Vira[535] et al., 2015).

At the local level, Cerri[536] et al. (2018) suggested that reduced deforestation, along with integrated cropland-livestock management, would positively impact more than 120 million people in Cerrado, Brazil. In Sub-Saharan Africa, where population and food demand are projected to continue to rise substantially, reduced deforestation may also positively affect food security (Doelman[537] et al., 2018).

These contributions vary according to the types of forests and how they are managed. Forest foods contribute to dietary quality and diversity and serve as safety nets in periods of food scarcity for those directly depending on forests for their livelihoods. Forests generate income for local people and provide essential ecosystem services for sustainable agriculture by regulating water flows, stabilizing soils, maintaining soil fertility, regulating the climate, and providing habitat for wild pollinators and predators of agricultural pests. The contribution of forests and trees to food security and nutrition has two main routes: direct and indirect.

Direct contributions include wild meat, fruits, and other food rich in micronutrients, providing invaluable components to rural diets, particularly for those households with less purchasing power. Evidence suggests that rural dwellers living near forests have more diverse and nutritious diets than those from more distal communities (Ickowitz[538] et al., 2014; Galway[539] et al., 2018). Further, agroforestry and tree-based agricultural systems contribute to securing food

---

[531] Bahar, N.H.A., Lo, Michaela, Sanjaya, M., Van Vianen, J., Alexander, Peter, Ickowitz, A., Sunderland, T. (2020) – Meeting the food security challenge for nine billion people in 2050: What impact on forests? *Global Environmental Change* 62: 102056.

[532] FAO, IFAD and WFP (2013) – The State of Food Insecurity in the World. FAO, Rome, 56 pp.

[533] Rowland, D., Ickowitz, A., Powel, B., Nasi, R., and Sunderland, T. (2017) – Forest foods and healthy diets: Quantifying the contributions. *Environ. Conserv.*, 44: 102-114.

[534] Sunderland, T.C.H. et al., 2013: Food security and nutrition: The role of forests. Center for International Forestry Research (CIFOR), Bogor Barat, Indonesia.

[535] Vira, B., Wildburger, C. and Mansourian, S. (eds.) (2015) - *Forests and Food: Addressing Hunger and Nutrition Across Sustainable Landscapes*. Open Book Publishers, Cambridge, UK, 280 pp.

[536] Cerri, C.E.P. et al., 2018: Reducing Amazon deforestation through agricultural intensification in the cerrado for advancing food security and mitigating climate change. *Sustainability*, 10: 989

[537] Doelman, J.C. et al., (2018) - Exploring SSP land-use dynamics using the IMAGE model: Regional and gridded scenarios of land-use change and land-based climate change mitigation. *Glob. Environ. Chang.*, 48: 119-135.

[538] Ickowitz, A., Powell, B., Salim, M.A., Sunderland, T.C.H. (2014) - Dietary quality and tree cover in africa. *Global Environmental Change* 24: 287–294.

[539] Galway, L.P., Acharya, Y., Jones, A.D., 2018. Deforestation and child diet diversity: a geospatial analysis of 15 sub-Saharan African countries. *Health Place* 51: 78–88

via increases in crop yield, supplying fodder and livelihood resilience (Reed[540] et al., 2017; Waldron[541] et al., 2017).

The indirect contribution of forests and trees includes providing essential ecosystem services that support food production. Marketable forest products also provide income to purchase food items and inputs for small-scale agriculture production.

The nexus between food security and forests has been mounting, culminating in two major policy processes. The first, published in 2015, was undertaken by the Global Expert Forest Panel of the International Union of Forestry Research Organisation (IUFRO) and provides "*evidence on how forests and tree-based landscape can be (and must be) an integral part of the solution on the global problem of food security and nutrition*". The second released by the UN Committee on World Food Security (2017) concluded that "*sustainable forestry is a key component of a sustainable food system*". This nexus is recognized (Fig. 49) by the Mediterranean Strategy for Sustainable Development (MSSD) (FAO/UNEP, 2018). Its vision responds to the need to orient the sustainable development agenda towards a "*prosperous and peaceful Mediterranean region in which people enjoy a high quality of life and where sustainable development takes place within the carrying capacity of healthy ecosystems*" (UNEP/MAP, 2016). It addresses also critical sectors, including rural and agricultural systems, in its second objective, "*promoting resource management, food production and food security through sustainable forms of rural development*."

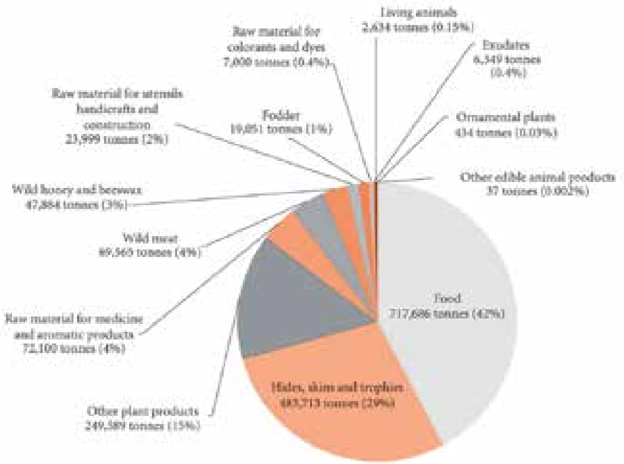


Fig 49 - Non-wood forest products removal in the Mediterranean countries (2010)
Source: FAO and Plan Blue, 2013[542]

Long term analysis has produced abundant evidence that agriculture, including forestry, is far from being sustainable. Truly much of humanity's progress has come at a considerable cost to the environment. To produce more food and other non-food agricultural goods, a combination

[540] Reed, J., van Vianen, J., Foli, S., Clendenning, J., Yang, K., Macdonald, M., Petrokofsky, G., Padoch, C., Sunderland, T. (2017) - Trees for life: the ecosystem service contribution of trees to food production and livelihoods in the tropics. *Forest Policy and Economics* 84: 62–71.

[541] Waldron, A., Garrity, D., Malhi, Y., Girardin, C., Miller, D.C., Seddon, N., 2017. Agroforestry can enhance food security while meeting other sustainable development goals. *Trop. Conserv. Sci.* 10, 1940082917720667 [https://doi.org/10.1177/1940082917720667].

[542] FAO and Plan Bleu (2013), *State of Mediterranean Forests* 2013, Rome, FAO.

of intensified agricultural production processes and the clearing of forests has led to the degradation of natural resources and is contributing to climate change.

The future will not look promising if we continue to address these challenges with a "*business as usual*" approach. Sustainable food and agriculture systems cannot be achieved without significant additional efforts and the support of a healthy and sustainable forest. Although the relevance of the links between forests, trees, food security and nutrition are now better understood, the importance of its contribution is yet to be accounted for and mainstreamed in both agricultural and forestry models. Most recently (COP27, 2021/11/02) Glasgow leaders' declaration on forests and land use "*recognise that our land use, climate, biodiversity, and sustainable development goals, both globally and nationally, will require transformative further action in the interconnected areas of sustainable production and consumption; infrastructure development; trade; finance and investment, and support for smallholders…*"

The importance of agroforestry systems regarding food security and various environmental benefits dimensions has been pointed out. As previously mentioned, the significance of the agroforestry systems representative of the Mediterranean, particularly in the south of Portugal and Spain, such as the Montado/Dehesa, must be stressed. Despite the long time this traditional agroforestry farming system has been practised and is still adopted in many parts of the Mediterranean region, considerable crop changes have occurred during the last 50 years across several Mediterranean areas driven by the increasing profitability of new farming crop options. Instruments to avoid land-use changes, require their evaluation as well as quantification of socio-economic impacts and generated externalities, along with the design of adequate compensatory mechanisms to be funnelled to owners.

The most significant LUC involved were the uprooting of ancient cereal farming and the mixed rotational farming systems were simplified and replaced usually by intensive monocultures. Instead of making agriculture greener, the CAP has actually encouraged its specialisation, leading to further intensification, accelerating farmland biodiversity (European Commission[543], 2019; Kindvall[544] et al., 2022; Santos[545] et al., 2023)

The increase in the number of cattle in the "montado" largely resulted from the support of agri-environmental measures of CAP to support extensive grazing in cork oak forests, which imposed a high stocking, between 0.15 to 1 normal head per hectare for ruminants and foraging pigs (Correia[546]et al., 2013). The additional payment of a subsidy to the suckler cow allowed for an increase in the cattle density, with a strong negative impact on the regeneration of the cork oak forest and with the rise in the import of feed concentrates for cattle.

Table 31 summarises the current scenario of the cork oak forests where it is evident the almost disappearance of agricultural culture undercover, the increase in both bush and pasture areas, and the high values of bare soil, mainly for stands with less arboreal cover. It is, in fact, a

[543] European European Commission, (2019) - Directorate-General for Agriculture and Rural Development, Evaluation of the impact of the CAP on habitats, landscapes, biodiversity: final report. *Publications Office, 2020*. [https://data.europa.eu/doi/10.2762/818843].

[544] Kindvall, O., Franzén, M., Askling, J., Forsman, A., Johansson, V., 2022. Subsidised Common Agricultural Policy grazing jeopardises the protection of biodiversity and Natura 2000 targeted species. *Anim. Conserv.* 25 (5): 587–607.

[545] Santos, M., Garcês, C., Ferreira, A., et al., 2023. Side effects of European eco schemes and agri-environment-climate measures on endangered species conservation: clues from a case study in mountain vineyard landscapes. *Ecol. Indic. 148, 110155.*

[546] Correia, T.P., Ribeiro, N.A., Potes, J. (2013) - O Livro Verde do Montado. Évora. Portugal

remarkable change in a very stable ecosystem landscape that requires careful attention to its control and recovery.

All these changes caused continuous pressure on the montado/dehesa environment, resulting in deficiencies in regeneration - often associated with an excess load of herbivores - and the precocious death of trees has reduced tree cover density and reduced biodiversity. This is proven by looking at stands with less than 40 trees/ha, which increased from 10% in 1995/98 to 30% of the cork oak area in 2005/06 (Pereira[547], 2014). The cork oak forests that are no longer profitable because of their low-density trees per hectare are generally abandoned. One must also mention the loss of wildlife-rich habitats and socio-economic viability over large parts of the region due to land abandonment by small-scale farmers.

When not acquired or appropriated for large landowners, these abandoned lands are now covered by bush and open forest plots without undercover crops (that constitute a dangerous substrate for the spread of rural fires, which are a high driver of soil degradation).

The worldwide information shows that increasing forest cover and decreasing deforestation rates are prerequisites for mitigating GHG emissions, increasing carbon sequestration and reducing global temperatures in the coming decades. It also showed the crucial role of forests in mitigating climate change. As this role has been widely recognized in recent years, it has become the central issue in global dialogue and forest policy processes. While the importance attached to carbon sequestration is today indisputable, it has also been recognized that a successful mitigation measure cannot leave behind the importance of underlying issues such as forest governance, land rights, extra-sectoral influences and integration of carbon payments into a broader multifunctional benefit stream. Today's dominant discussion on sustainable forest management goes far beyond its initial focus on forest carbon sequestration (and its measurement), underlining the need for holistic approaches rather than focusing solely on forest carbon.

Table 31- "Montados" undercover type according to the degree of tree cover (2015) (1,000 ha)

Cover Species	Undercover type	Young Trees	[10,20]	[20,30]	[30,40]	[40,50]	[50,60]	[60,70]	≥70
Cork oak	agriculture	0.1	3.1	1.9	1.1	0.3	0.1	0.1	0.0
	bushes	1.5	30.8	27.5	27.4	16.3	8.0	.1	0.0
	pasture	4.4	103.8	133.8	129.9	76.7	33.8	16.4	0.0
	Bare ground	9.0	39.6	11.7	6.2	4.2	2.9	2.0	0.0
	n. identified	1.2	1.7	1.1	0.6	0.4	0.3	0.2	16.5
Holm oak	agriculture	0.0	7.7	2.5	0.6	0.2	0.0	0.0	0.0
	bushes	0.1	19.9	17.6	11.1	4.4	2.2	1.7	0.0
	pasture	0.2	93.2	95.4	56.1	16.5	3.6	1.7	0.0
	Bare ground	0.3	3.2	0.8	0.4	0.3	0.1	0.1	0.0
	n. identif	0.0	1.9	0.5	0.8	0.4	0.4	0.1	5.6

Data source: 6º Inventário Florestal Nacional. Relatório Final [6th National Forest Inventory, Final Report], ICNF, 2015

[547] Pereira, J. Santos (2014) – O Futuro da Floresta em Portugal. Fundação Francisco Manuel dos Santos, Lisboa, Portugal 110 pp.

Despite the recognition of the positive mitigation effects of forests, it was found that in Portugal, the projected forest cover is decreasing, not meeting the growing demand for wood and cellulose products and other services, namely in terms of improving biodiversity, reducing erosion in mountainous areas, or protecting soil health. So, targets such as the Aichi Targets, the Bonn Challenge, the New York Declaration on Forests and other zero-deforestation commitments and restoration of degraded forest landscapes (e.g. Mediterranean Forest Week[548] in 2017) are not being met by Portuguese Forests. This is not difficult to infer, given the amounts of aid directed to forestry activities, which decreased by 13.9% in 2019 and that Gross Fixed Capital Formation[549] (GFCF) decreased in volume (-6%) and value (-5.3%) due to the component afforestation and reforestation that evolved negatively (-12% and 11.6% in volume and value, respectively).

Among ecosystem services provided by forests and trees, it is essential to highlight the importance of the sink capacity of forests since it can make a significant and cost-effective contribution toward climate change mitigation. However, agricultural systems can also offer mitigation benefits and contribute to forest sparing. A recent global study of trees on rural land suggested a large carbon stock that has so far been overlooked in accounting (Zomer[550], 2016). Agroforests and adapted soil management represent a promising potential for sink and mitigation. Several measures and activities related to these potentials have been implemented, showing their effectiveness without compromising agricultural production.

In the present context of climate change, the contribution of the Portuguese LULUCF carbon sink to the global balance of carbon emissions in Portugal must be stressed (Fig. 50).

The National Inventory of GHG Emissions due to LULUCF for 2019 indicates that in 2019, forests have helped to retain an average GHG of 10.38 Mt CO_2 eq. In years of major fires, the primary role of the forest sector, which starts to function as a GHG emitter, is reversed. Table 32 depicts the disaggregated sink values for LULUCF expressing differences due to species, area covered and tree morphology.

The international recognition of the multidimensional importance of forests led in 2003 to the creation of the Global Partnership on Forest and Landscape Restoration (GPFLR) for the restoration of forests and landscapes, to support and influence global policy to broaden thinking about forests and the importance of reforestation beyond industrial plantations and communities-level woodlots.

The Global Partnership on Forest and Landscape Restoration (GPFLR), is widely viewed by international agencies and organizations as a means toward reaching the 2030 agenda for Sustainable Development of the UN, the National Determined Contribution of countries to the Paris Climate Agreement (Bonn[551] Challenge, 2011), that pledge to bring 350 million ha of

---

548 In the Mediterranean Forest week in Morocco, nine countries (Algeria, France, Iran, Lebanon, Morocco, Portugal, Spain, Tunisia and Turkey) endorsed the Agadir Commitment thereby agreeing to restore 8 million ha of degraded landscapes by 2030.

549 Economic Forestry Accounts, 2019, INE, 2021

550 Zomer RJ, Neufeldt H, Xu J et al. (2016) - Global tree cover and biomass carbon on agricultural land: the contribution of agroforestry to global and national carbon budgets. *Sci. Rep.* 6, 29987

551 Bonn Challenge (2011) – Available online: http://www.bonnchallenge.org/content/challenge (accessed on 17 September 2015)

deforested and degraded land into restoration by 2030. Tools and guidelines to support Forest and Landscape Restauration (FLR) planning, and adaptation are proliferating (FAO[552], 2020).

Initiatives based on GPFLR are underway in Latin America, the USA, Africa, and the Mediterranean (Cruz-Alonso[553], et al., 2019). In this effort, Portugal, as far as we could investigate, did not pledge any action under the GPFLR umbrella.

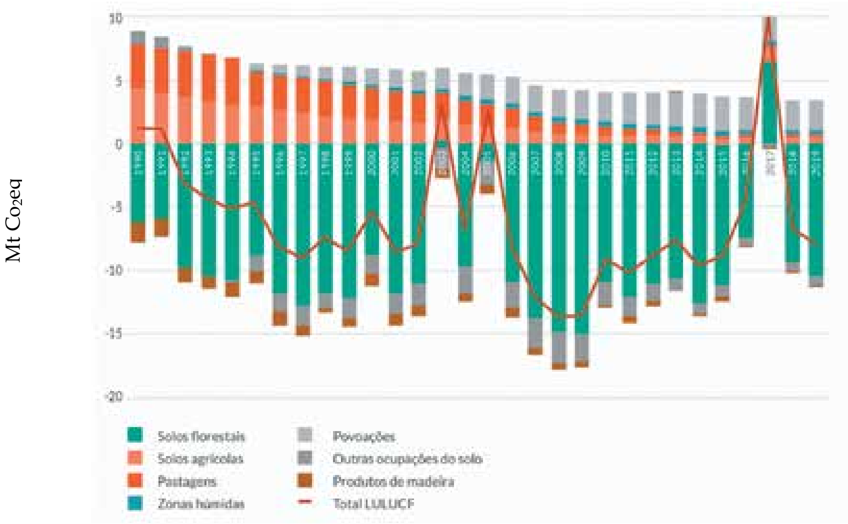


Fig. 50 – Evolution of GHG removals and emissions from the LULUCF sector in Portugal (Mt CO_2eq). Data source: Agência Portuguesa do Ambiente, <u>*2021 National Inventory Report.*</u>

Table 32 - Carbon sequestered by land use and species (2015)

Species	Living biomass		Dead biomass				
Gg CO_2eq							
	Tree	Undercover vegetation	Standing trees	Fallen trees	Stumps	Litter	Total
Forest	305.46	21.78	5.37	1.06	0.471	0.101	333.92
Maritime pine	82.46	5.66	1.69	0.30	0.166	0.033	90.3
Eucalypts	63.64	6.61	0.61	0.33	0.228	0.037	71.4
Cork oak	62.87	4.34	0.72	0.11	0.016	0.006	68.0
Holm oak	17.97	1.72	0.29	0.03	0.002	0.002	20.0

552 FAO (2020) – The Forest and Landscape Restoration Mechanisms Knowledge Base. [available online: http://www.faoorg/in-action/forest-landscape-restoration-mechanism/knowledge-base/monitoring-evaluation/en/2020]

553 Cruz-Alonso, V., Ruiz-Benito, P, Villar-Salvador, P., Rey-Benayes, J.M. (2019) – Long-term recovery of multifunctionality in Mediterranean forest depends on restoration strategy and forest type. J. appl. Ecol. 56: 745-757.o

Table 32 - Carbon sequestered by land use and species (2015) (continuation)

Oaks	13.26	0.51	0.09	0.01	0.012	0.004	13.9
Stone pine	16.96	1.08	0.07	0.02	0.008	0.005	18.1
Chestnut	14.83	0.20	1.54	0.00	0.003	0.002	16.6
Carob Trees	1.14	0.09	0.00	0.00	0.000	0.000	1.2
Acacias	4.77	0.04	0.18	0.01	0.001	0.000	5.0
Other broadleaves	20.68	1.22	0.13	0.23	0.029	0.009	22.3
Other resinous	6.67	0.31	0.06	0.02	0.006	0.002	7.1
Non-forest land uses	8.51	23.01	0.20	0.23	0.00	0.060	32.01
Agriculture	6.30	22.65	0.02	0.23	0.00	0.06	25.06
Bushes and pastures	2.09	0.04	0.00	0.00	0.00	0.00	0.04
Unproductive	0.01	0.30	0.18	0.00	0.00	0.00	6.78
Urban	0.11	0.02	0.00	0-00	0.00	0.00	0.13

Data source: 6º Inventário Florestal Nacional. Relatório Final [6th National Forest Inventory, Final Report], ICNF, 2015

The integrated approach to address threats and degradation factors in Mediterranean forests through the Forest and Landscape Restoration (FLR) methodology focuses on choosing appropriate interventions to achieve ecological functionality and human well-being in the context of landscape units in intervention. This approach considers the compromises between agricultural and forestry production, environmental conservation, and social well-being, ensuring the best possible integration at the landscape level. FLR fully recognizes that forests are a landscape component that interacts with other elements.

In the context of climate change, FLR can be combined with adaptation techniques to anticipate the changes that forest ecosystems would have undergone if they had not been degraded. While it is recognized that forests and trees alone are not sufficient to ensure global food security, they can play a significant role. Reform and implement policies that reflect this paradigm shift that is occurring in many places where landscape management, on a multifunctional basis, harmoniously ensures food production, biodiversity conservation and maintenance of ecosystem services, significantly contributing to improving Global food and nutritional security is an absolute necessity for Portugal if it wants to restore its forestry and restore and sustain its land use capacity.

In practice, results emerge from the interaction of land uses at the landscape scale, recognising the need to balance the trade-offs in land use through a multisectoral approach and including all groups and interested parties in the decision-making process. The nature of FLR practice is considered relevant to achieving a significant scale concerning the multiple objectives that the forest must play in climate mitigation and helping improve food vulnerability.

Substantial funds flow into large international organisations and countries to support FLR programmes and projects. From 2004 to 2015, over $US 8 billion of private capital was committed to conservation and forest restoration to generate both financial return and environmental benefits. Moreover, the corporate sector continues to engage in carbon and biodiversity offsetting strategies linked to reforestation and conservation projects on the ground (Koh[554], 2019).

Given the variety of goods and services provided by the Portuguese forests, the diversity of actors involved in their management, and the numerous opportunities for forest restoration in Portugal, FLR methodologies seems a particularly relevant forest-based solution worth exploring.

While forests are recognized as a pillar for sustainable agriculture, food security and improved nutrition that cannot be achieved at the expense of and without forests, conversion from land use to agriculture, driven by increased demand for food and degradation of the soils, remains the leading cause of global deforestation, accounting for 70-80 per cent of total forest loss with adverse impacts on the environment and millions of peoples, local communities, and smallholders.

The critical need to halt this degradation across countries, including Portugal, calls for better coordination of land use policies to promote sustainable agriculture that benefits from healthy, sustainable, and productive forests and tree ecosystems within landscape mosaics as guarantors of more resilient food security in the general context of achieving the 2030 goals of the Agenda for Sustainable Development.

Influential coordination challenges countries, particularly in Portugal, where the problems of forest degradation are manifestly worrying, to rethink sensibly and on a national scale, using an agile and adequately thought-out organizational model.

Restoring degraded forests, reforestation, and afforestation, the three forest-based options to mitigate climate change, are gaining momentum globally and have become a relevant international policy topic in the forest sector and a significant component of nature-based climate solutions (Cohen-Shacham[555], et al., 2019). Additional options under adaptation strategies include i) reducing emissions from deforestation, ii) reducing emissions from forest degradation, iii) enhancing forest carbon sinks, iv) well-managed forests, v) product substitution adaptation, vi) making forests more resilient to climate change, and vii) using forests sustainably (i.e. decreasing the vulnerability of forest-dependent people to climate change).

The ambitious goals set at the 21st Conference of Parties (COP) of the United Nations Framework Convention on Climate Change (UNFCCC) in Paris have been discussed in Bonn and Marrakesh. The Road Map for Global Climate Action notes a long-term move in focus. The Marrakesh Action Proclamation[556] (2016) promises actions in the agriculture sector, primarily ensuring food security and enhancing the ability to deal with the impacts of climate change on agriculture. There was further progress on agriculture in Bonn; the links between agriculture and climate change were included as a discussion point, with options such as increasing soil carbon being mentioned. At the same time, the Paris Climate Agreement (PA) features forest-based mitigation as a key mitigation strategy and works to secure food production. The admission of a de facto synergy of both subsectors mitigates the potential conflicts between forests and agriculture, as has often been seen in Portugal.

---

[554] Koh, N.S., Hahn, T., Boonstra, W.J. (2019) – How much of the market is involved in a biodiversity offset? A typology of the biodiversity offset policies. *J. Environ. Manag.* 232: 679-691.

[555] Cohen-Shacham, E., Andrade, A., Dalton, J., Dudley, N., Jones, M. et al. (2019) – Core principles for successfully implementing and upscaling Nature-based Solutions. *Environ. Sci. Policy* 98: 20-29

[556] Marrakech Action Proclamation for Our Climate and Sustainable Development (2016) [unfcc.int/files/meetings/Marrakech_nov_2016/application/pdf/Marrakech_action_proclamation.pdf]

Glasgow COP26 (2021) strengthened the ties between forests and agriculture, avoiding competition for land, inefficiencies in monitoring, and conflicting agendas that would result in looking separately at agriculture for food security within a changing climate and on forests for climate change mitigation and adaptation. The potential of different mitigation options may vary considerably among regions, and prioritisation depends on local considerations. In general, preventing forest loss seems to be a quick and cost-effective choice in those areas with significant rates of deforestation and degradation, provided it does not merely shift deforestation to other places. The success of this approach could be determined by how it is used to address opportunity costs and other socio-political-economic issues.

Diverging from EU and other Mediterranean countries and international efforts to increase and restore forest area, the Portuguese forest situation presents a divergent scenario; its forest area, which increased significantly from the 1890s to around 1980, begins decreasing progressively, in the order of -0.3 % year-1 between 1995 and 2015 (Table 17, pp. 131) and further decreased with the dramatic fires of 2017, 2021 and 2022. Although the forest sector's GNP contribution to the Portuguese economy has reduced, it is still vital. It still feeds a very active industry in which wood pulp and paper, sawn timber and pallets, pellets, particleboard panels, various plywood and cork products stand out. Despite that importance, the solid wood industry, which depended heavily on maritime pine, whose area has suffered severe degradation due to forest fires, suffers from shortages in the supply of raw wood material. The deficit of pinewood represented, in 2020, 57% of industrial consumption, or 2.3 million m3 (AIMMP[557], 2021). In the forestry sector as a whole, the pine sector continues to stand out due to its high employability rate, representing 80% of jobs in the forestry industries and providing 57,078 jobs in 8,578 existing companies. The pulp and paper industry are also feeling raw material shortages and needs to import more than 2 million m3 /year of raw wood to supply the installed capacity of their industries.

Fig. 51 illustrates the intensity of forest fires from 2015 to 2018, where the high toll suffered by the two principal industrial wood raw materials (maritime pine and eucalyptus) is evident.

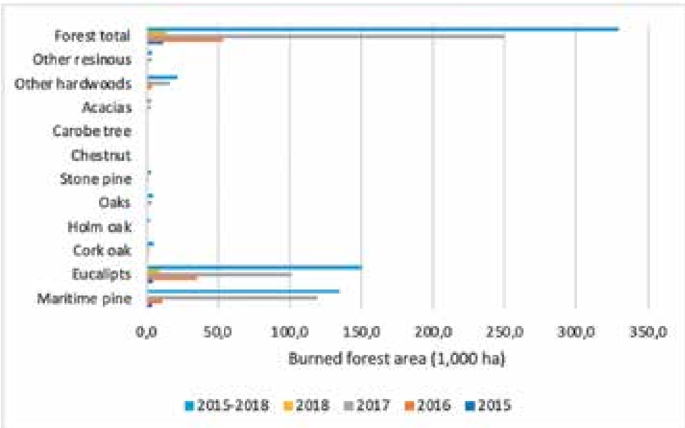


Fig. 51 – Burnt forest areas in Portugal by species (2015-2018)

---

[557] AIMMP (2021) – Escassez de pinho e subida dos preços ameaça indústria da madeira. Statements by the President of the Portuguese Wood and Furniture Industry Association in an interview with the daily "O Público". [https://publico.pt/2021/11/14/economia/noticia/escassez-pinho-subida-precos-ameaça-industria]

A prospective analysis carried out by Uva[558] (2015) maintaining a business-as-usual (BAU) scenario in which the driving forces for alteration and intervention capacity remain unaltered shows the severe risk of calamitous regression of the Portuguese forest area and the composition of its cover. This analysis reveals that by 2050 Portuguese forest could be reduced to 2707 thousand ha, about that existing in 1950 (Fig. 52).

Under the conditions mentioned, the resinous area could regress to around 378 thousand ha. The vegetation cover will be restricted to two dominant types: cork oak and holm oaks forests (evergreen-leaved trees) and eucalyptus (Forest-industrial hardwoods), each with about 1 million ha. These changes in forest land use will have a profound economic and social impact in Portugal.

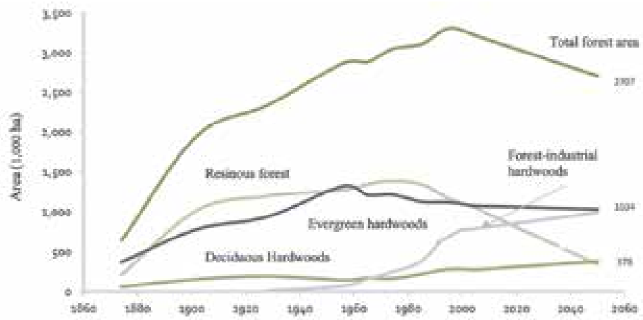


Fig. 52 - Forthcoming trends in the evolution of Portuguese forest cover under prevailing driving forces

Data source: Uva (2015)

A failure to address these threats and drivers of degradation will eventually lead to a loss of the natural capital provided by forests and trees outside forests in Portugal and a profound socioeconomic impact on the forestry sector and the Portuguese trade balance. It is also essential to highlight the loss of the significant contribution of forestry externalities that result from the absence or slowness in implementing mitigation and adaptation strategies to climate change. However, forest-based solutions can already help combat this decline in Portuguese forests. The bottlenecks preventing the implementation of new dynamics fundamentally lie in the insufficiencies of public policies, forestry strategies and intervention structures that should play an essential role and are hardly compatible with those that have existed for almost two decades.

Foreseeable changes in forest areas and composition will directly impact carbon stocks and undesirable climate trade-offs: increased erosion in the river basins, increased flood events, and decreased water infiltration biodiversity reductions. A study carried out by Cunha[559] et al. (2021) showed that under a BAU scenario supported by an increase in eucalyptus forests and a decrease in pines and other evergreen hardwoods, it would result in a reduction of carbon sequestration of about -2.7 %, particularly in Lisbon region, Algarve, and Northern region.

The maintenance and enhancement of the Portuguese forest sector and fulfilment of the Portuguese international commitments seem to point to priority in the planning of restoration of

[558] Uva, José (2015) - Inventário Florestal Nacional. A dinâmica da ocupação florestal do solo desde o século XIX a 2050. *Cadernos de Análise Prospetiva. Gabinete de Planeamento, Políticas e Administração Gera*l. No. 2: 83-91

[559] Cunha, J., Campus, F. S., David, J., Pandmanaban, R. & Cabral, P. (2021) – Carbon sequestration scenarios in Portugal: which way to go forward? Environmental Monitoring Assessment 193, Article number 193. [https://doi.org/10.1007/s10661-021-09336-z]

degraded forests, mitigation, and adaptation actions. Forest sector mitigation is related to promoting the storage and sequestration of carbon in standing trees and long-lived wood products, using wood, and increasing, where possible, the supply of bioenergy or biochar, restoration, afforestation and decreasing forest degradation.

In Portugal, the frequency and intensity of fires in recent decades have polarized most of the discussions on how to prevent forest fires, minimizing consideration of the remaining damage caused by other natural disturbances, whose occurrence tends to increase due to climate change, which also entails economic losses for owners and, in addition, to the amenities for society. As for the latter's loss, the damage affects the forests' overall carbon sequestration capacity. These impacts could become even more critical shortly since extreme natural events' frequency, duration, and intensity will likely increase with climate change (IPCC[560], 2021). Given that forest ecosystems play a significant role in mitigating the effects of climate change through carbon sequestration, there is a genuine concern about how this mitigation capacity can be maintained and reinforced as risks increase. If the current rates of forest intervention are maintained, it seems unlikely that the Portuguese forestry sector will be able to keep up with the pace of climate change. So, there is an urgent need to remove the current bottlenecks that are rooted in an almost total absence of adaptation strategies, in the implementation of innovative management models and in a timely reforestation/afforestation strategies that can positively maintain the mitigation of climate change and the commitments assumed by the Portuguese authorities in these matters.

Adaptation aims to reduce risks and improve the resilience of ecosystems and their goods and services. Ecosystem services can contribute to Mediterranean forest adaptation in several ways (well-managed forest, better genetic resources, good use of NWFP, watershed purification and regulation of flow during dry seasons and flood flow during rain events, carbon sink) (FAO, 2014). There is a broad consensus that forest disturbances are sensitive to climate change, which makes it urgent to think about mitigation and adaptation measures that make forests more resilient to disturbances induced by climate change.

Several adaptation strategies have been proposed elsewhere to maintain forest ecosystems' resilience, such as reducing coppice rotation duration and decreasing stand density (Bolte[561], et al., 2009). In climatic situations like ours, this strategy presupposes more intense and frequent human intervention in stands to avoid an increase in the growth of understory biomass, without which the vulnerability of forest stands to forest fires would increase. Furthermore, the depopulation of the territory in the interior does not seem conducive to the choice of solutions of this type.

Diversification is another strategy that can be used to protect trees from climate fluctuations and climate change-induced disturbances, contributing to the development of more stable forest stands. Two types of diversification can be considered. One refers to composition diversification, which is also mentioned as forest conversion, entailing shifting from extensive monocultures to mixed stands with at least two species, looking for complementarities in the canopy structure

[560] IPCC, (2021) – Climate change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. In: Dellmote, Masson, Zhai, V., Pirani, A., Connors, S.J., Péan, C., Berger, S., Caud, N.,Chen, Y., Goldfarb,I., Gomis, M.J., Huang, M., et al., (eds.). Contribution of the Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press.

[561] Bolte, A., Ammer, C., Löf, M., Madsen, G., Nabuurs, G.J., Schall, P., Spathelf, P., Rock, J. (2009) – Adaptative forest management in Central Europe: climate change impacts strategies and integrative concept. Scand. J. For. Res. 24(6): 473-482

(canopy packing), Jucker[562] et al., 2015), which in turn can increase tree resistance to damage. The mixing verified with the apparent success of cork oak and stone pine goes in this direction. Indeed, different vertical rooting patterns among species can result in higher water uptake and greater stand resistance to wind, which deserves special attention in semiarid regions. Some authors also found that mixing species in a stand could increase forest productivity and other ecosystem services such as carbon sequestration (Kirby[563] and Potvin, 2007; Lange[564] et al., 2015). In any case, the potential positive or negative effects (increased competition for water) seem to depend on the context (e.g. nature of the soil, climate) and the mix of species used, which requires an active, well-functioning and well-endowed forestry research organization.

A second type of diversification is structure high forest diversification (or forest transformation), which modifies the stand structure by introducing different diameter classes within the same stand. Moving from even-aged to uneven-aged silviculture increases the stability of the entire stand structure (Hanewinkel[565] et al., 2014). The same authors mentioned that this strategy enhances stand resilience to natural hazards since the understory trees allow faster recovery after disturbance. However, an uneven-aged forest management regime can increase the vulnerability of stands, particularly in areas prone to frequent winds. Subsequent cutting interventions reduce the stabilizing effect of contact with the canopy that usually occurs in even-aged stands. (Mason[566] and Valinger, 2013). However, the literature still lacks sufficient robust information on whether diversification of forest stands can be used as an economically effective adaptation strategy in response to future drought and windstorm-induced risks from a private forest owner's perspective respecting timber production and carbon storage. In fact, the traditional economic approach considers one hazard at a time, not considering the possible interactions between hazards, whereas their effects could be significant due to climate change since it is known that this also favours the interactions between disturbances. As mentioned by Seidl[567] et al. (2017), the increase in temperature due to climate change increases drought risk in some regions, which, in turn, increases vulnerability to insect attacks and directs the insect population's growth rate. This makes it necessary to consider interactions between types of hazards as an emergent and non-linear phenomenon, separate from the study of individual risks.

Some authors (e.g. Bastit[568] et al.,2023) mentioned that future disturbances will likely be most pronounced in coniferous forests and the boreal biome. The general framework points to climate change effects on important abiotic (fire, drought, wind, snow and ice) and biotic (insects and

---

562 Jucker, T., Bouriaud, O., Coomes, D.A. (2015) – Crown plasticity enables trees to optimize canopy packing in mixed-species forest. *Funct. Ecol.* 29 (8): 1078-1086.

563 Kirby, K.R. and Potvin, C. (2007) – Variation in carbon storage among tree species: implications for the management of a small-scale carbon sink project. For. Ecol. Manag. 246 (2-3): 208-221

564 Lange, M., Eisenhauer, N., Sierra, C.A., Bessler, H., Engels, C., Griffiths, R.I., Mellado-Vásquez, P.G. et al. (2015) – Plant diversity increases soil microbial activity and soil carbon storage. Nat. Commun. 6(1): 1-8.

565 Hanewinkel, M., Kuhn, T., Bugnann, H., Lanz, A., Brang, P. (2014) – Vulnerability of uneven aged forests to storm damage. Forestry 87 (4): 525-534.

566 Mason, B., Vallinger, E. (2013) – Managing forests to reduce storm damage, 87-96. In: Gardiner, B.A., Shuck, A., Schelhaas, M.J., Orazio, C., Blennow, K., Nicoll, B. (eds), Living with Storm Damage to Forests, What Science can Tell Us 3, EFI Joensuu [available at: https://portal.research.Ju.se/files/6513888/Living_with_storm_damage_to_forests.pdf]

567 Seidl, R., Thom, D., Kautz, M., Martin-Benito, D., Peltoniemi, M., Vacchiiano, G., Wild, J., Ascoli, D., Petr, M., Honkaniemi, J., Lexer, M. J., Trotsiuk, V., Mairota, P., Svoboda, M., Fabrika, M., Nagel, T.A., & reyer, C.P.O. (2017) – Forest disturbances under climate change. *Nature Climate Change* 7: 395-402.

568 Bastit, Félix, Brunette, M., and Montagné-Huck, C. (2023) – Pests, wind and fire: a multi-hazard risk review for natural disturbances in forests. *Ecological Economics*, Volume 205, 107702.

pathogens) disturbance agents and that warmer and drier conditions mainly facilitate fire, drought and insect disturbances. In comparison, warmer and wetter conditions increase disturbances from wind and pathogens. Given the fragility and dispersion of efforts in our forestry research, our understanding of the disturbance dynamics in response to climatic changes remains incomplete, particularly regarding large-scale patterns, interaction effects and dampening feedback.

Widespread interactions between agents are likely to amplify disturbances, while indirect climate effects such as vegetation changes can dampen long-term disturbance sensitivities to climate.

Although international forestry research is undoubtedly a significant contributor to Portuguese forestry, it is important to remember that forestry impacts and yields are highly contextual, which advises against ready-made solutions, meaning that Portuguese forestry activity should be accomplished with much higher support from national research. In the context of climate change, the corresponding policy should also consider an adequate institutional and legal framework to integrate challenges in conserving forest goods and services with a consequential financial portfolio.

In this regard, it would be good not to forget the advice issued years ago by the FAO[569] (2007) that the framework for addressing the effectiveness of adaptation measures must encompass in an integrated manner several interconnected lines of intervention, namely:

- Legal and institutional elements – decision-making, institutional mechanisms, legislation, implementing human rights norms, tenure and ownership, regulatory tools, legal principles, governance and coordination arrangements, resource allocation, and networking civil society.
- Policy and planning elements – risk assessment and monitoring, analysis, strategy formulation, and sectoral measures.
- Livelihood elements – food security, hunger, poverty, non-discriminatory access.
- Cropping, livestock, forestry, fisheries and integrated farming system elements – food crops, cash crops, growing season, crop suitability, livestock fodder and grazing management, non-timber forest products, agroforestry, aquaculture, integrated crop-livestock, silvopastoral, water management, land use planning, soil fertility, soil organisms.
- Ecosystem elements – species composition, biodiversity, resilience, ecosystem goods and services.
- Linking climate change adaptation processes and technologies for promoting carbon sequestration, substituting fossil fuels, and promoting the use of bioenergy.

At this stage and maintaining a business-as-usual attitude, we may say that both ecosystems and society should be prepared for an increasingly disturbed future for Portuguese forests.

Although forest owners and users have long recognized that forests provide a series of environmental and social benefits, in addition to wood and fibres, edible, medicinal plants and hunting, the fact is that some of these public goods that are not appropriated by the market do not contribute to encouraging producers to improve their holdings or to adopt fire prevention measures.

---

[569] FAO (2007) – Adaptation to climate change in agriculture, forestry and fisheries: Perspective, framework and priorities. FAO, Rome, 32 pp.

Forests have traditionally been seen primarily as producers of tangible goods. It was only relatively late that we increasingly began to understand that, in addition to these primary functions, they are also crucial in providing human society with intangible services of high value, such as soil protection, flood control, the fight against desertification, climate stabilization and pleasant landscapes. However, ecology and economics have failed to standardize the definition and measurement of ecosystem services. One of the failures of the forestry profession, in the words of Burley[570], (1994), has been its inability to account for these values not appropriated by the market and to demonstrate to policymakers the total economic values of the forest and the need for long-term commitments in research, education and career prospects for technicians, accompanied by appropriate incentives and material resources.

Under current climate change threats, the loss of Forest Ecosystem Services (FES) provided by forests and not appropriated by landowners is one of the main reasons for the abandonment of small forests. Many unaccounted-for valuable goods and services with variable life cycles (Fig. 53) are not commoditized, meaning forest owners are reimbursed only for direct use values, which are only a portion of the goods generated by its forests. (Fig. 54).

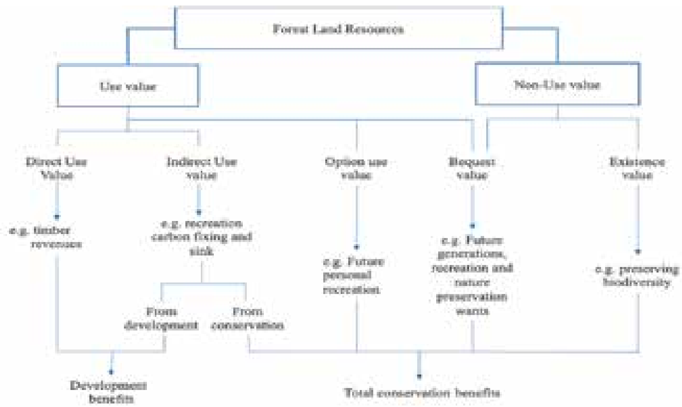


Fig. 53
Breakdown of different woodland values
Source: Bateman and Turner571 (1993)

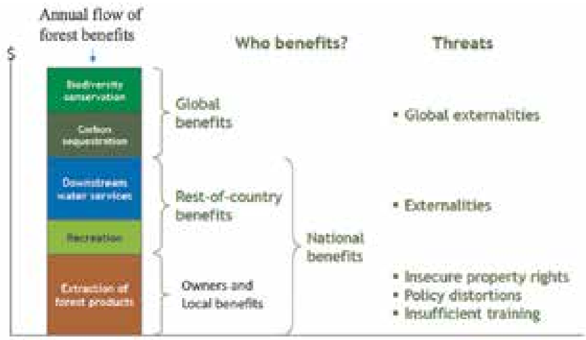


Fig. 54 – Simplified scheme of the annual forest flow of benefits and beneficiaries
Source: Adap. from Pagiola (2018)

---

570 Burley, J. (1994) – World Forestry: The Professional Scientific Challenges. The Leslie L. Schaffer Lectureship in Forest Science. Vancouver: University of British Columbia, April 1994

571 Bateman, Ian J. and Turner, R. K. (1993) – Valuation of the Environment, Methods and Techniques: The Contingent Valuation Method, 120-191. In: R. Kerry Turner (ed.), Sustainable Environmental Economics and Management. Principles and Practice. Belhaven Press, 389 pp.

According to many studies, the "services economy" will be the driving force of social development in this century, and it is time to understand that the balance between the importance of tangible forest products and intangible forest services will tip in favour of the latter, particularly in relatively high-income countries like those of EU (Florio[572], 1987).

As most of the forest area in Portugal is private and distributed by numerous smallholders, a central tenet to help contain land abandonment and contribute to effective conservation and maintaining a proper flow of environmental goods and poverty reduction of smallholders, is to transfer to them the corresponding values of the services provided by forest ecosystems and its fair distribution. To address this issue, including commitments and negotiations will require expanding the scope of the forest sector to include this wide range of stakeholders.

However, a fundamental question that underlies the intervention capacity of forestry supervisory authorities in Portugal is knowing the role that the State wants to assume as a facilitator, encourager, and regulator of market solutions for ecosystem services or forms of valuing forest resources in the context of a green and circular economy. This systemic rethinking of the role of the forest and the consequent organization of the planning, implementation and monitoring structure is still incomplete; it is confusing because of the numerous actors and the scarcity of research in these areas. From a scientific point of view, this field is relatively unexplored, which means that the authorities cannot safely evaluate forestry investments needed in this area and follow a consistent cost/benefit approach. This means they would invest real money and are groping in the dark. Under these conditions, supply and demand would be balanced in the darkness. To cope with this challenge, we need a consistent social and forest economic-political analysis research strategy.

During the last three decades, since the publication of the Millennium Ecosystem Assessment in 2005 (www.maweb.org), a significant increase of international publications on Forest Ecosystems Service (FES) has been made available (Pagiola[573] and Platais, 2007; Potschin[574] and Haines-Young, 2010).

The publication of The Economics of Ecosystems and Biodiversity Report of 2010 (www.teebweb.org) has added more interest to this field. Both reports, together with other seminal contributions of Constanza[575] et al. (1997), Pagiola[576] et al. (2002), Weber[577] (2014) and WB[578] (2014), have significantly advanced the conceptual framework, modelling and valuation of FES and the development of instruments to incorporate Ecosystem Services (ES) concepts in management practices and policymaking.

---

[572] Florio, M. (1987) – The Forest Resource in the European Community: Scenario Analysis, Long-Term Challenges, Strategic Options. Final Report of the FAST Forestry Network Activity, nº 169, 195 pp.

[573] Pagiola, S., and Platais, G. (2007) – Paymments for Environmental Services. From Theory to Practice. Washington: World Bank.

[574] Potschin, M.B. and Haines-Young, R.H. (2010) - Ecosystem services: exploring a geographical perspective. *Progress in Physical Geography* 35: (575-594)

[575] Constanza, R., et al., (1997) - The value of the world's ecosystem services and natural capital. *Nature*, 1997. 387(6630): p. 253-260.

[576] Pagiola, Stefano, Bishop, J., and Landel-Mills, N. (2002) – Selling Forest Environmental Services. Earthscan Publications Ltd. 299 pp.

[577] Weber, J.L. (2014) - Ecosystem natural capital accounts: a quick start package. Technical Series No. 77, Secretariat of the CDB, Montreal. 248 pp.

[578] WB (2014) - Designing Pilots for Ecosystem Accounting. World Bank WAVES project. Washington: World Bank

An evaluation of the importance of FES in some Mediterranean countries, including Portugal (Fig. 55), reveals their relative importance vis-à-vis the direct forest market goods (Croitoru[579] and Merlo, 2005) and the potential importance of a thorough analysis of its possible utilization for dynamizing the anaemic Portuguese forest producer yields.

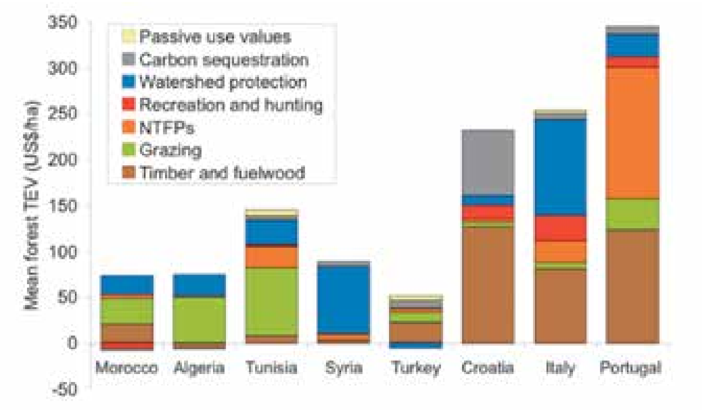


Fig. 55- Total Forest values in some Mediterranean countries (Mean annual flow of benefits from Mediterranean forests = US $ 148/ha) (Croitoru and Merlo, 2005)

According to Madureira[580], *et al*. (2021) from 2014 to 2019, excluding 2017, the average Total Economic Value (TEV) was, by default and at 2016 prices, 2.240 billion euros. Subtracting from this value and in the period mentioned, the social costs of forest fires (prevention, combat and losses of goods and services), that average value was 1.900 billion euros. As for 2017, the most disastrous year of fires this century in Portugal, (TEV) was negative (-77.795 M€).

In the same period, not considering the year 2017, the percentages of the values of non-market goods and services included in the TEV were, in percentage terms, 50.09% in 2014, 46.35% in 2015, 43.48% in 2016, 47.30% in 2018 and 49.85% in 2019. In average terms, these percentages represent 1.062 billion euros for the Portuguese forest as a whole, that is, an average value of 173.52 €/ha.

The breakdown of the values of non-market goods and services, carried out within the scope of the ECOFOR project, by species or groups of species, revealed that softwoods and eucalyptus represent around a fifth of the TEV, cork oak, and holm oak represent a quarter and the other hardwoods forests and pastures about a third.

The summary in Figure 56 breaks down the percentage contribution, by year and type, of non-market goods and services to the TEV.

Despite the information available, we assist that even in the absence of perverse public policies, forest environmental services (FES) are mostly non-marketed commodities not appropriated by the market due to their nature as externalities or public goods. So, a complete monetary evaluation designed to 'price' all spectrum of the environmental goods and services

---

579 Croitoru, L and Merlo, M. (2005) – Mediterranean Forest Values. Chap. 3. In: L. Merlo and L. Croitoru (eds), Valuing Mediterranean Forests. Toward Total Economic Value. CABI Publishing. 448 pp.

580 Madureira, L., Sottomayor, M., Rosario, J.V., Alves, M.R.P., Mura, S.S.A., Mendes, Américo (2021) – ECOFOR.PT – Valorização Económica dos Bens dos Ecossistemas Florestais de Portugal. Relatório Científico. Católica Business School – CEGEA – Centro de Estudos de Gestão e Economia Aplicada, 193 pp.

provided by the forest and its devolution to forest owners, mainly the tiny holders duly integrated into organizations capable of guaranteeing proper sustainable exploitation, would be an incentive to better forest management and restoration actions. Indeed, compared to previous approaches to forest conservation, participative market-based mechanisms have the potential for increased effectiveness and equity in distributing costs and benefits.

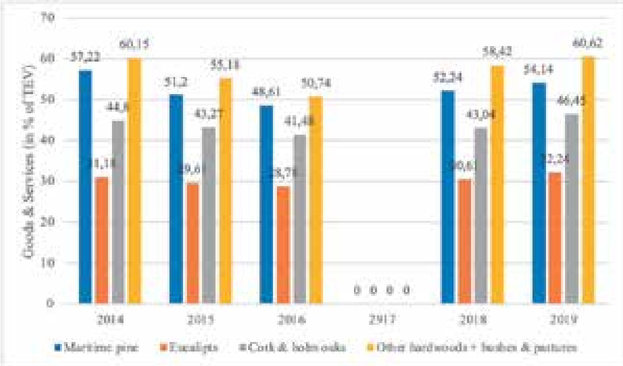


Fig. 56 - Breakdown by year and species of the value of non-market goods and services in the Portuguese forest
Data source: Madureira et al. (2021)

Experience with market-based instruments shows that if carefully designed and implemented, such policies can achieve environmental goods at significantly less cost than conventional command-and-control approaches while creating pragmatic bases for continual improvement and innovation (OCDE[581], 1993; Stavins[582], 1999).

There is already a wide range of FES assessment methodologies and instruments suitable for its funding, addressing each of the services in question and illustrating their application problems, but whose approach is outside the scope of this review. In merely descriptive terms, we explain the fundamental principles of its application. The logic of the market-based mechanism is illustrated in Fig. 57, exemplifying two market mechanisms related with payment of ecosystems services (PES): one that sells carbon sequestration and the other that sells sedimentation services to downstream water users.

---

581 OCDE (1993) – *Economic Instruments for Environmental Management in Developing Countries*. Proceedings of a Workshop held in OECD Headquarters in Paris, 8 October 1992. Organisation for Economic Co-operation and Development, Paris.

582 Stavins, R.N. (2000) – Experience with Market-based Environmental Policy Instruments. In: K. G. Mäler and J. Vicent (eds.), *The Handbook of Environmental Economics*. Amsterdam: North-Holland

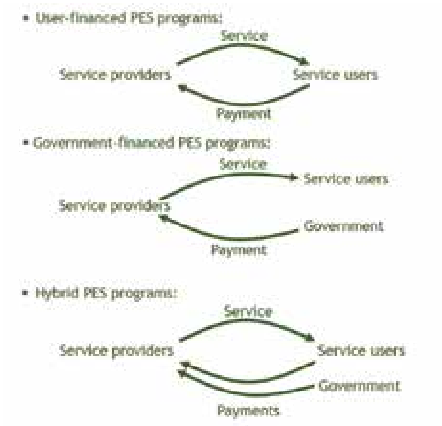


Fig. 57 – Principles of market mechanism for payments for environmental mechanisms
Source: Pagiola (2018)

Note that payments for forest environmental services (PES) programs are not designed to be a poverty reduction mechanism in favour of small owners but to address ecological and natural resource management problems by providing means to internalize externalities. Although, they certainly can contribute to pro-poverty reduction (Bracer[583] et al., 2007). Two aspects of PES programs are particularly noteworthy from their potential impact on poverty in rural areas.

- Payments made under PES programs are usually payments to land users. This makes the distribution and ownership patterns of land critical for the poverty impact of PES programs.
- Land user participation in PES programs is voluntary, and participants receive payments for delivering a contractualized environmental service. This creates a *prima facie* presumption that participants are at least no worse off than they would be without the PES program. If this is not the case, they may simply refuse to participate.

Compared to previous frameworks, the PES concept adopts a more holistic landscape view in which the interconnections with other land uses are made more explicit through the conditionality of rewards. This conditionality is a primary difference between PES and simple subsidies. In PES schemes, the service provider must be bound by a contract to evaluate their eligibility for payment and be rewarded only when they provide a service. Both buyers and sellers must also agree on the level of efficiency and fairness of the PES mechanism. Experience of several world examples of the application of PES mechanisms shows that if buyers (e.g. hydroelectric dams) after a few years wonder what they are paying for, or if the sellers start to see the payments as an entitlement, the scheme is likely to collapse, as Van Noordwijk[584] et al. (2008) note. What began as a financing instrument for sustainable forest management may become unsustainable.

---

[583] Bracer, C., Scherr, S., Molnar, A., Sekher, M., Ochien, B.O. and Sriskanthan, G. (2007) – Organizing and Governance for Fostering Pro-Poor Compensation for Environmental Services: CES Scoping Study Issue Paper no. 4. ICRAF Working Paper no. 39. World Agroforestry Centre, 52 pp.

[584] Van Noordwijk, Leimona, Beria, Hoang, Minh Ha, Villamor, G. and Yatich, T. (2008) – Payments for environmental services. pp. 95-100. In: Holopainen, Jani and Marieke Wit (eds.) – Financing Sustainable Forest Management. Tropenbos International, Wageningen, The Netherlands, 176 pp.

Diversification of production and income is crucial for spreading risk and helping vulnerable rural populations cope with environmental disruptions and economic crises. In the Portuguese case, small and medium-sized forestry holders or companies play a critical role in local economies, help alleviate poverty and provide significant rural employment that must be maintained and strengthened in the face of the foreseeable increase in climate risks. Therefore, it is imperative to create the necessary conditions and technical support to increase adaptive capacity and livelihood resilience for rural small-land owners to maintain their forest holdings. This is done by providing policy support to develop varied and effective coping mechanisms and incentives, such as SEF payments.

In this context, we should note the importance of the scale of forest intervention units and the interconnection between environmental, economic, and social issues, which underlines the importance of working in an integrated manner for all sectors in addressing ecological, social, and economic problems. The landscape is a valuable unit to work in an integrated way on this issue, highlighting the importance of organizational aspects and institutional arrangements. One must remember that small forests are embedded into a broader landscape influenced by a range of biophysical, social, and institutional forces in large parts of our territory. Working at the landscape level is conducive to cohesively building the resilience of land systems, natural resources, and people's livelihoods (FAO[585], 2012). Understanding the potential for decentralised dynamics between the different elements (biophysical, social, economic, and institutional) and engaging local stakeholders in decision-making, will help develop strategies and actions that induce resilience and adaptation to climate change and present itself as an adjuvant for territorial cohesion. Although almost all of the countries of the Mediterranean have developed national strategies and plans to drive a shift to the sustainable management of natural resources, there is a general lack of a long-term comprehensive and integrated vision for their implementation (Lacirignola[586] et al., 2017).

In our case, forest management policies and other inland natural resources are often sectorial, fragmented, and prone to applying ready-made solutions to issues that are interconnected, thus failing to embrace a larger vision, including the management and maintenance of the forest infrastructure, distribution schemes, access to technology, the training of farmers and dissemination of knowledge, wood pricing policies and the monitoring and evaluation of the implemented measures. More generally, the current situation shows a lack of awareness and knowledge among many involved stakeholders, limited availability of up-to-date data, the absence of monitoring and evaluation processes, the fragmentation of responsibilities and a lack of coordination between different authorities, and shortages of financial and human resources as factors hindering the adoption and implementation on the integrated forest, agriculture, and food security vision.

Concerning biodiversity, forests are known to hold large parts of the terrestrial biodiversity, and the conservation of this unique heritage is not only a matter of economics but also a matter of culture and ethics. Several recent studies have reported a positive effect of tree species diversity

---

[585] FAO (2012) – Forest, trees and people together in a living Landscape: a key to rural development. Committee on Forestry Paper COFO/2012/6.2 Landscape: a key to rural development. Committee on Forestry Paper COFO/2012/6.2 [http://www.fao.org/docrep/meeting/026/me435e.pdf]

[586] Lacirignola, C., Lamaddalena, N., Khadra, R., (2017) – *Water Scarcity and Security in the Mediterranean*, Chapter 1. In: *Water around the Mediterranean* UfM-Revolve Report. [https://ufmsecretariat.org/wp-content/uploads/2018/01/water-reprot-2017.pdf]

on forest productivity at a global scale (e.g. Zhang[587] et al., 2012; Liang[588] et al., 2016). Furthermore, forest biodiversity contributes to many ecosystem services, from providing material and energy to regulating abiotic and biotic disturbances. Jactel[589] et al. (2017) found that overall, the productivity of mixed-species forests was 15% greater than the average of their component monocultures and not statistically lower than the productivity of the best component monoculture. Productivity gains in mixed-species stands were not affected by tree age or stand species composition but significantly increased with local precipitation. The results should guide better use of tree species combinations in managed forests, suggesting that increased drought severity under climate change might reduce natural forests´ atmospheric carbon sequestration capacity.

Although far from well understood, it is evident that diverse forest ecosystems provide many advantages over monocultures, especially when considering multiple functions that should be maintained at different places and times and with a more substantial reason in those sites that are more sensitive to climate changes, such as, for example, the cork and holm oak forest. Economic valuation of biodiversity function will contribute significantly to better recognition of biodiversity value. In addition to conservation values, it can form a basis for payments for biodiversity-related ecosystem services. However, Achten[590], et al. (2011), mentioned that biodiversity function should not be used as an alibi for neglecting 'non-functional values' of biodiversity – the so-called intrinsic value of nature.

However, beyond this question, it is widely acknowledged that forest biodiversity contributes to climate change mitigation through improved carbon sequestration. However, conversely, how climate affects tree species diversity and forest productivity relationships is still poorly understood since divergent results were found. However, recent cutting-edge research is unravelling the functional significance of forest biodiversity for sustained delivery of ecosystem services with extensive scale tree diversity experiments in Germany, Finland, Belgium, France, Panama, Malaysia, China, and Canada (www.treedivnet.ugent.be). As can be seen, Portugal's absence from international initiatives in favour of forests is notorious. Next to an experimental platform, the FP7 project FunDivEurope (www.fundiveurope.eu) also includes an exploratory platform, where over 200 plots with different tree species diversity levels were carefully selected in mature forests distributed over six contrasting regions ranging from Finland to southern Spain. This network of plots forms the backbone of forest biodiversity function research, the most significant innovation in forest biodiversity studies in recent years.

Also, for forest management and forest policy, Ecosystem Services (ES) advancement studies provide an added value as they further extend and operationalize existing concepts of multifunctional and sustainable forest management brought forward in global (e.g. United Nations Forum on Forests), regional (Ministerial Conference on the Protection of Forests in Europe) and sub-national policy documents.

---

587 Zhang Y., Chen, H.Y.H., Reich, P.B. (2012) - Forest productivity increases with evenness, species richness and trait variation: a global meta-analysis. *J. Ecol.* 100, 742 – 749. [doi:10.1111/j.1365-2745. 2011.01944.x]

588 Liang, J. et al. (2016) - Positive biodiversity-productivity relationship predominant in global forests. *Science* 354, aaf8957. [doi:10.1126/science.aaf8957]

589 Jactel H., Gritti, E.S., Drössler, L., Forrester, D.I., Mason W.L., Morin, X., Pretzsch, H., Castagneyrol, B. (2018) - Positive biodiversity– productivity relationships in forests: climate matters. *Biol. Lett.* 14: 20170747. [http://dx.doi.org/10.1098/rsbl.2017.0747]

590 Achten, W., Verbist, B., Aerts, R., Kint, V., Hermy, M., Poppe, J., Marx, A., Van-Orshoven, J., Verheyen, K., et al. (2011) – Conservation and Management of Forest for Sustainable Development: Where Science Meets Policy. Mataforum Leuven. Interdisciplinary think-tank K.U. Leuven. Hollands College, 44 pp.

Furthermore, ES science has initiated the development of new tools to quantify, map and value the relevant services generated by forests for a given area and to reward sustainable land users for the ES they provide through different payment schemes.

Although forest management and forest policy may benefit from adopting the ES framework, several conceptual and methodological challenges must be overcome before they can be fully translated into practice. Further research is necessary into the status and, especially, process indicators for forest ecosystem functioning and ecosystem service delivery. Better insights in dealing with spatial-temporal scaling issues are required, too, i.e. what is the most appropriate scale to quantify a particular ES and the interactions between different scales and between other ES (trade-offs vs synergistic effects). Although it is already available and tested methodology to operationalize ES concept ecosystem service valuation, and especially turning values into prices, it is still very challenging since non-market appropriate values are difficult to monetarized just as the quantification of direct and indirect use values are still a matter of debate (Spangenberg[591], and Settele, 2010). Despite that, there is the certainty that standardization of ES's definition and measurement systems is necessary. Clear units of account are fundamental to realizing policy initiatives whose social desirability we consider to be self-evident: the effective acquisition of environmental quality by governments and clear national measures of well-being arising from environmental public goods and market goods - also known as green GDP measures.

In the global context of European Union policies, rural development is presented as central and strategic since they are capable of interfering with a wide range of areas, such as the Common Agricultural Policy, food sustainability, the protection of the environment, the circular economy, the implementation of the UN Programme for Sustainable Development 2030 and climate change.

The European Parliament approved, on 8th October 2021, a report addressing various issues relating to forests. Among the matters analysed is the role of the forestry sector in fulfilling the objectives of the European Ecological Pact, fire prevention, rural exodus and the importance of the CAP, the financing of forestry measures and research programs for livelihoods, as well as the growth of the bioeconomy in rural areas.

The European Commission (EC) presented in July 2021 the future EU Forest Strategy that replaces the EU Forest Strategy adopted in 2013 and evaluated in 2018. This new strategy sets a vision and concrete actions to improve the quantity and quality of EU forests and strengthen their protection, restoration, and resilience. It aims to adapt European forests to the new conditions, weather extremes, and high uncertainty brought about by climate change, one of the flagship initiatives of the European Green Deal and builds on the EU biodiversity strategy for 2030. The EU's strategy aimed to achieve the EU's biodiversity objectives of at least 55% by 2030, and the GHG emission reduction target, and climate neutrality by 2050. It recognises the central and multifunctional role of forests and the contribution of foresters and the entire forest-based value chain to achieve a sustainable and climate-neutral economy by 2050 and preserve lively and prosperous rural areas). This report is a wake-up call. MEPs warn that "*an ambitious, independent and autonomous EU Forest Strategy for the post-2020 period is needed*" and call for "*measures to curb deforestation worldwide and to encourage not only reforestation and afforestation but also the sustainable management of forest resources*".

The Commission recognised that sustainable raw wood and non-wood materials and products, and FES as well, are essential in the EU’s transition to a sustainable climate-neutral

591 Spangenberg J.H. and Settele, J. (2010) - Precisely incorrect? Monetizing the value of ecosystem services. *Ecological Complexity*, 7: 327-337.

economy and that sustainably produced and long-lived wood-based products can help to achieve climate neutrality by storing carbon and substituting fossil-based materials, in particular through their embodied carbon add to carbon removal that otherwise takes place through biological processes.

The EC also recalls that when building a sustainable and climate-neutral economy, it is crucial to optimise the use of wood in line with the cascading principle, mainly through market incentives.

This means that wood should be used as much as possible for long lifecycle materials and products, to replace their carbon-intensive and fossil-based counterparts, for example, in buildings and furniture, whilst acknowledging that not all wood is fit for such a purpose. The processing innovations in this field can also provide bio-based materials and products with a lower environmental footprint than fossil-based ones. Short-lived wood-based products also have a role to play, especially in substituting their fossil-based counterparts. The wood used for the production of short-lived products and of bioenergy or biochar, should rely on wood residues unsuitable for long-lived materials and products. The same goals could be achieved by secondary woody biomass such as sawmill residues, and recycled materials. Technological advances already facilitate the processing of woody biomass residues and waste for circular innovative materials and products, thus diversifying the bio-based products and offering climate-friendly solutions for new or emerging application areas.

At the national level, global and European political trends are presented in several national instruments. We refer in particular: i) National Low Carbon Roadmap (NLCR 2050); ii) Strategic Framework for Climate Policy (QEPiC) which includes, among others, the National Program for Climate Change 2020/2030 (PNAC 2020/2030), the National Strategy for Adaptation to Climate Change (ENNAC 2020) and the Green Commitment (CCV); iii) the National Strategy for Air (2020) and iv) the National Strategy for the Conservation of Nature and Biodiversity to 2030 (ENCNB 2030).

In line with these political and economic guidelines, the national role of the agricultural and forestry sectors (LULUCF sector) could be decisive within the scope of rural development and territorial cohesion policy. The negative trend that has been witnessed in Portugal in terms of land use seems to call for the urgency to establish a new paradigm for agricultural and forestry policies based on the implementation of improvements in agricultural and forestry practices and the promotion of carbon conservation in soils and forests, but also in promoting markets, land, structures and organization solutions that can boost land use.

The trends on LULUCF show that the elaboration of strategic documents is insufficient without their operationalization at the level of regions and farmers. The case of Portuguese forest evolving in a way contrary to that of the EU is clear. Portuguese forestry sector authorities face a fundamental challenge in structuring the intervention and monitoring services. The design of a new forestry planning and research structure can reverse the downward trend in the Portuguese forestry sector.

The recent "legislative reform of the forest", although expressing concern about the sustainability of the forest and the incentives for sustainable forestry production, does not, however, present instruments aimed at promoting the profitability of forest spaces in the context of forest environmental services, nor the restructuring of a cohesive operating structure. Essentially, except for fire-fighting measures, the reform is limited to the attempt to organize the forest territory - characterized by a multitude of smallholdings resulting from insuficiencies of inhertance law- through the simplification of the regime for the creation of forest intervention zones (Decree-Law 67/2017), the amendment of the legal rule for the recognition of forest management entities and respective incentives (Decree-Law 66/2017, amended by Law 111/2017).

The legislation is, however, silent on the quantification of targets and a multi-temporal financial package. It still lacks measures to encourage the payment of environmental services and private intervention to explore new ways of making the forests more profitable, in line with the guidelines of the green economy and the circular economy. The only measure to promote the profitability of the forest that is included in the Government's legislative package is the legal rule for new forest biomass plants for the production of thermal and electrical energy with supported prices (Decree-Law 64/2017), a solution that, according to experts, is not even in track with best practices for the use of forest by-products (OECD[592], 2018).

8.2 - Climate change and challenge of sustainable development

Climate change and sustainable development are challenges to Portuguese society that require action at local, national, transboundary, and global scales. Different time perspectives are also crucial in decision-making, ranging from immediate actions to long-term planning and investment. Acknowledging the systemic link between food production and consumption and land resources more broadly is expected to enhance the success of actions. Because of the complexity of challenges and the diversity of actors involved in addressing these challenges, decision-making would benefit from a comprehensive portfolio of policy instruments. Decision-making would also be facilitated by overcoming barriers such as inadequate education and funding mechanisms and integrating international commitments into all relevant national sectoral policy decisions. 'Nexus thinking' emerged as an alternative to the sector-specific governance of natural resource use to achieve global security of water (D'Odorico[593] et al. 2018), food and energy (Hoff[594] 2011; Allan[595] et al. 2015), and to address biodiversity concerns (Fischer[596] et al. 2017). Significant barriers remain to establishing nexus approaches as part of a more expansive repertoire of responses to global environmental change, including challenges to cross-disciplinary collaboration, complexity, political economy and the incompatibility of current institutional structures.

Collectively, the SDGs provide a framework to eradicate poverty, eliminate inequalities and combat climate change on the path to a sustainable, inclusive and fair future for all. Given the global interactions of economics, politics and the environment, the international community,

---

[592] OCDE (2018) – Meeting Policy Challenges for a Sustainable Bioeconomy Paris, 199 pp. [http://dx.doi.org/10.1787/9789264292345-en]

[593] D'Odorico, P., Davis, K.F., Rosa, L., Carr, J.A., Chiarelli, D., Dell'Angello, J., MacDonald, G.K. et al. (2018) – The Global Food-Energy-Water Nexus. *Rev. Geophys*, 56, 465-531, [doi:10.1029/2017RG000591]

[594] Hoff, H. (2011) - Bonn 2011 Conference: The Water, Energy and Food Security Nexus – Solutions for the Green Economy. Stockholm, 1–52 pp.

[595] Allan, T., Keulertz, M. and Woertz, E. (2015) The water–food–energy nexus: An introduction to nexus concepts and some conceptual and operational problems. *Int. J. Water Resour. Dev.*, 31, issue 3: 301-311, [doi.org/10.1080/07900627.2015.10029118].

[596] Fischer, J., Abson, D.J., Bergsten, A., Collier, N.F., Dorresteijn, I., Hanspach; J. et al. (2017) - Reframing the Food-Biodiversity Challenge. *Trends Ecol. Evol*., 32, 335–345, [doi.org/10.1016/j.tree.2017.02.009].

under the auspices of the UN, has agreed that achieving the SDGs requires global cooperation guided by the Charter of the United Nations as a way of developing viable international cooperation to improve and advance the 2030 Agenda for Sustainable Development, without forgetting, however, that the most important level of decision-making remains in the nation-state that holds the primary responsibility for achieving the SDGs.

States were required to meet a series of challenging performance indicators to achieve the SDGs. Yet, indicators and political declarations must be coupled with clear commitments and effective investments in concrete actions to attain monitored progress. Even before the covid-19 outbreak, several countries were registering deficient performance in areas such as Food Security and Sustainable Agricultural Production (SDG 2), Access to Water (SDG 6), the Development of More Sustainable Production and Consumption Models (SDG 12) or the Fight Against Climate Change (SDG 13).

These components that must implement effective policies that are also part of the Portuguese government's commitment to the SDGs (2015-2030) were far from being met, as shown in Fig. 58.

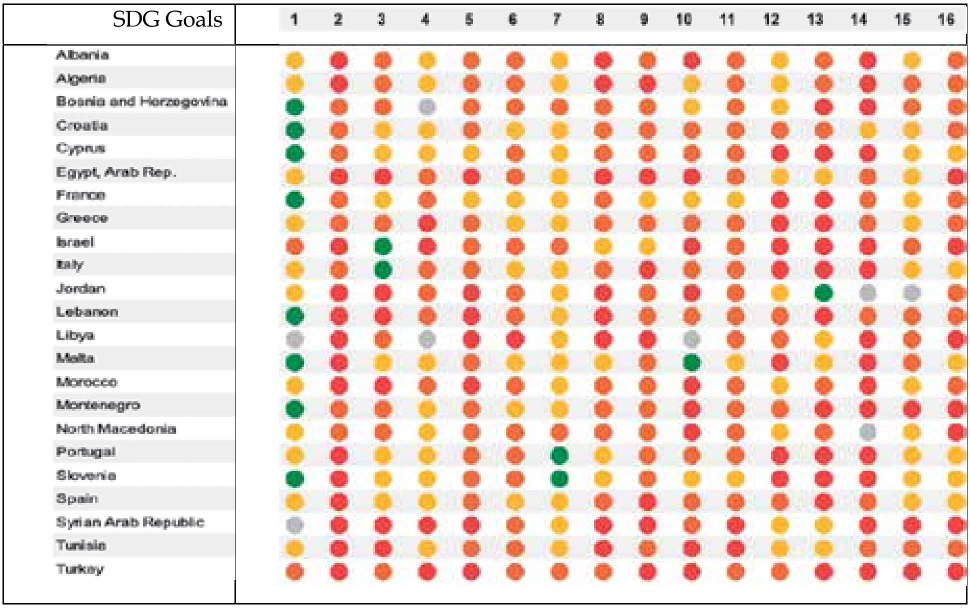


Fig. 58 - Sustainable Development Goals dashboard for Mediterranean countries (2019)
Legend: Green = on track or maintaining SDG achievement; Yellow = moderately improving; Orange = stagnating; Red = decreasing; Grey = information not available.
Source: Sachs[597] et al., Sustainable Development Report 2019, cit., p. 19-47

[597] Sachs, Jeffrey D. et al. (2019) - *Sustainable Development Report 2019*. Mediterranean Countries Edition, Siena, Sustainable Development Solutions Network Mediterranean (SDSN Mediterranean), [https://www.sdsn-mediterranean.unisi.it/?p=1290]

Eleven years to go before the completion of the Sustainable Development Goals (SDGs), the Mediterranean countries were not on track in meeting the vast majority of seventeen SDGs. Subscribed to by all member states of the United Nations back in 2015, SDG aims for an unprecedented transformation of our societies.

Although the objectives were slow to achieve, progress on the SDGs has stagnated globally since the outbreak of the pandemic in 2020 and other simultaneous crises. Portugal is no exception to this slow progression in achieving the SDGs; poverty, unbalanced inequalities, and dispersed uncoordinated structures between the different regions of Portugal currently hinder sustainable development and climate resilience.

To support local and vulnerable communities and give consistency to territorial cohesion policies to contain further human desertification and the abandonment of agricultural and forest spaces, climate adaptation and environmental resilience policies need to incorporate justice, equity, poverty reduction, social inclusion, and redistribution (The First Mediterranean Assessment Report (MAR1, 2020).

Since the outbreak of the pandemic in 2020 and other simultaneous crises, SDG progress has stalled globally underscoring the interdependency between human development and the environment and the impact that unsustainable consumption and economic models are having on both. The grim reality is that at the midpoint of the 2030 Agenda, the SDGs are far off track. As of 2022, the global SDG Index is below 67% and it is foreseeable that at current trends, based on simple projections, there is a risk that the gap in SDG outcomes between HICs and LICs will be wider in 2030 (29 points) than it was in 2015 (28 points). This means that we are at risk of losing a decade of progress towards convergence globally.

At the global level, averaging across countries, not a single SDG is currently projected to be met by 2030, with the poorest countries struggling the most. Even in most highly income countries, only limited progress is being made on the environmental and biodiversity goals, including SDG 12 (Responsible Consumption and Production), SDG 13 (Climate Action), SDG 14 (Life Below Water), and SDG 15 (Life on Land), even in countries that are largely to blame for the climate and biodiversity crises (Sachs[598], et al., 2023).

The world is also seriously off track to meet the Paris Agreement climate targets and SDG 13. Global warming as of 2022 stood at 1.2 ºC, with warming continuing at more than 0.3 ºC per decade. At this rate, the likelihood of overshooting 1.5 ºC, even within a decade, is robust. According to the UNEP[599] Emissions Gap Report 2022, current policies put the world on track to reaching a disastrous 2.8 ºC warming by 2100. If implemented, current Nationally Determined Contribution (NDC) targets would still lead to around 2.4 ºC warming by 2100. Even considering the net-zero pledges of many countries, best-case scenarios given current pledges would lead to around 1.8 ºC warming by 2100 (Fig. 59).

The impact of the pandemic was equally severe on Portuguese society and economy, which was also reflected in the slow evolution of mediocre progress in achieving the objectives, as reflected in Portugal's SDG score index in achieving the goals it proposed, as summarized in Figure 60.

[598] Sachs, J.D., Lafortune, G., Fuller, G. and Drumm, E. (2023) – Sustainable Development Report 2023. Implementing the SDG Stimulus. Paris: SDSN, Dublin: Dublin University Press, 545 pp.

[599] UNEP (2022) – Emission Gap Report at https://www.unep.org/resources/emissions-gap-report-2022

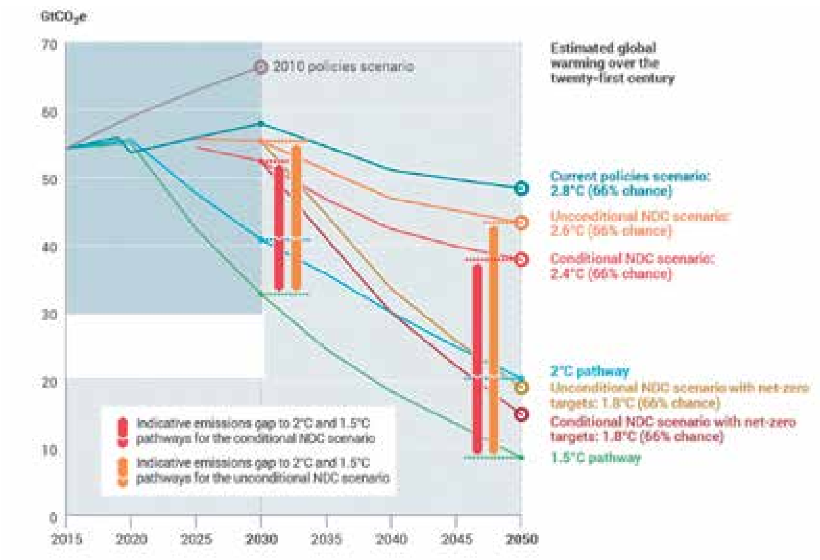


Fig. 59 - Projected global warming under alternative policy scenarios
Data Source: UNEP, Emission Report 2022

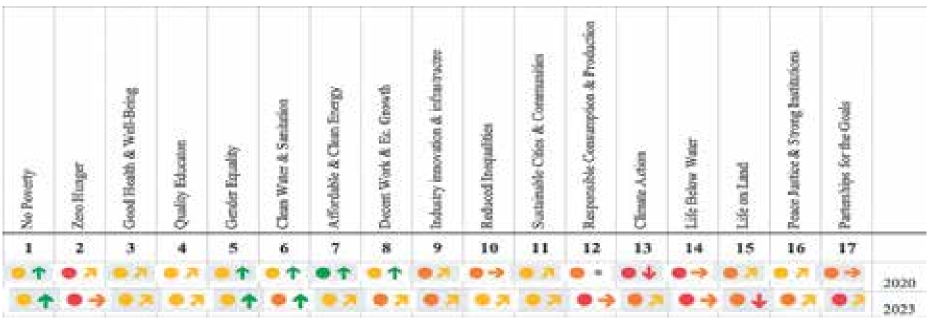


Fig. 60 – Portugal's SDG dashboards (levels and trends, 2020 & 2023)

Data source: Sachs[600]at al. (2020) and Sachs et al. (2023)

Concerning SDG objective 13 (Climate Action), there is even a retraction in fulfilling the committed goals for that objective. Clearly, only multilateral frameworks based on cooperative approaches and a degree of solidarity can engender positive momentum towards addressing these issues. Yet, Mediterranean countries are at very different economic and social development levels, with some being industrialized or service-driven economies with low energy intensity and

[600] Sachs, J., Schmidt-Traub, G., Lafortune, G, Fuller, G., Woelm, F. (2020) - Sustainable Development Report 2020. Cambridge: Cambridge University Press. 520 pp.

others grappling with poverty, unemployment, poor infrastructure, and a lack of access to essential services, like reliable energy supply.

These divergences complicate the task of conceiving a common climate approach in the Mediterranean and even formulating observations that can be applied to the region, let alone finding standard solutions. Moreover, the weak integration, particularly in trade and infrastructure connectivity across southern and eastern Mediterranean states, adds further challenges to efforts to favour cooperative approaches to mitigate these challenges. Therefore, it is no coincidence that Mediterranean conditions are generally not on track for achieving the SDGs, as shown in Table 33. On the one hand, they seem to perform well for some indicators like poverty eradication, the promotion of good health and well-being and quality education. On the other, we can see alarming performances concerning biodiversity protection, including life below water and life on land particularly; social integration, including gender equality and the fight against all forms of inequality; and the promotion of sustainable agriculture and diets, or like us, in containing climate action and forest degradation.

Table 33 – The SDG index: score and rank (2023)

Countries	Score	Ranking		Countries	Score	Ranking
Europe West				Middle East		
France	82	6		Israel	74.0	48
Greece	78.4	28		Jordan	69.0	77
Italy	78,8	24		Lebanon	67.5	95
Malta	75.5	41		Palestine	--	--
Portugal	80.0	18		Syria Arabic Republique	58.2	130
Spain	80.4	16		Turkey	70.8	72
Europe East				North Africa		
Albania	73.5	54		Algeria	70.8	71
Bosnia & Herzegovina	74.0	47		Egypt	69.6	81
Croatia	81.5	12		Libya	--	--
Cyprus	72.5	59		Morocco	70.9	70
Montenegro	71.4	67		Tunisia	72.5	58
North Macedonia	72.5	60				
Slovenia	81.0	13				

Data source: *Sustainable Development Report 2023* [The SDG Index is an assessment of each country's overall performance on the 17 SDGs, giving equal weight to each Goal; The score signifies a country's position between the worst possible outcome (score of 0) and the target (score of 100)].

Achieving sustainability in the Mediterranean basin, recognised as the second most vulnerable region in the world to climate change after the Arctic, is critical to ensuring thriving, resilient societies and more stable and secure states and social contacts. The region is subject to several forms of vulnerability ranging from the political to the economic, social, and environmental domains, with due differences across geographic areas.

As shown in Part I of this review, Mediterranean countries, including Portugal, are also one of the areas in the world with the most significant problems of water scarcity and limited arable land, most of which is heavily dependent on unpredictable rainfall. Climate change will further increase water stress and food insecurity as declining rainfall affects irrigated agriculture, decreasing crop yields. Therefore, it is urgent to design mitigation and adaptation measures where reforestation, afforestation and restoration of degraded soils and forests become essential.

Addressing sustainability is also essential to better understand this region's social, political, environmental, and economic fragilities. When coupled with the multidimensional impacts of climate change, these may lead to new or renewed conflicts or social unrest, as the recent history of some parts of the region attests. Resource scarcity, urbanisation and demographic decline are significant challenges to already stressed governmental policies and finances. Meanwhile, persistent political divisions and the existence of several hot, frozen, and not-too-frozen conflicts – from Israel-Palestine to Western Sahara, Libya, and Syria and the energy and water demarcation disputes in the Eastern Mediterranean – continue to represent formidable challenges to region-wide multilateral approaches aimed at fostering sustainable development and cooperation.

All countries across the Mediterranean area are in urgent need of identifying a common language that speaks to the local, national, and regional dimensions of the multiple overlapping challenges at stake, working to develop holistic approaches that begin from a careful appreciation of pre-existing fragilities and how climate change can act as a threat multiplier in many of these contexts. All said underscores the need for comprehensive, cooperative approaches to address sustainability-related challenges at a theoretical level and, most importantly, in practical terms.

The social, economic, and environmental dimensions of sustainability must be considered and collectively inform future endeavours to foster sustainable development in Portugal for the COVID-19 recovery phase and beyond. Despite Portuguese EU membership, it is undeniable that Portugal's inclusion in the Mediterranean would greatly benefit from enlarged cooperation in tackling several pressing issues where energy and climate take central stage in these efforts. The energy transition is a challenge but can also be transformed into an opportunity for economic development and enhanced north-south cooperation across the Mediterranean, potentially even becoming a means to de-escalate geopolitical tensions, such as those emerging in the Eastern Mediterranean. Hydrocarbon producers (e.g., Algeria, Egypt, and Libya) will be particularly exposed to the challenge of transitions to green energy. Still, if adequately managed and linked to growing funding and support from critical international organizations, such efforts can help place these states and societies on more sustainable economic growth trajectories. Meanwhile, the emerging opportunities made available by renewable energy – and the growing emphasis on shortening supply lines and promoting a greener and more just recovery for the post-pandemic world – may provide new impetus for new forms of integration and cooperation across Mediterranean states.

It is with these thoughts in mind that the New-Med Research Network, a multi-year research, outreach and dissemination project run by the Rome-based Instituto Affari Internazionali (IAI) with the support of the Italian Ministry of Foreign Affairs and International Cooperation (MAECI), the Organization for Security and Cooperation in Europe (OSCE) Secretariat in Vienna and the Compagnia di San Paolo Foundation, has directed increased emphasis on investigating the interlinkages between climate change, state and societal resilience and security in the Mediterranean region. The OSCE’s growing focus on the implications of climate change for comprehensive security must be looked at attentively to shed light on the challenges faced by sustainability in this region and the nexus between climate change, sustainability, and human security across the Mediterranean.

Embarking on the multinational participation provided by the institutions mentioned above is a clear challenge for Portuguese institutions, which have to think more and more about the dimension and complexity of the problems that must be approached on a new scale.

Annex I
The forest territorial occupation in Portugal: its troubled history

Throughout history, the origins of community lands "*Baldios*" have been lost in time due to the Christian reconquest, and their extended maintenance can be attributed to various factors, including historical legacies, cultural practices, and legal structures influenced by Roman and Byzantine traditions. Local communities typically organized and managed these lands, ranging from small villages to large cities. They were recognized as a community resource, with rights and responsibilities shared among community members.

In medieval times, in Mediterranean countries, community land ownership emerged as a response to the socioeconomic challenges of the time. Community lands provided the foundations upon which societies' social cohesion and identity developed, fostering a sense of community identity and solidarity, serving as meeting points for community events and traditional practices and promoting cultural preservation. Furthermore, for centuries, the communal ownership model in Mediterranean countries allowed for the sustainability of agricultural practices, ensured food security for local populations, and addressed socioeconomic disparities. However, many institutions traditionally responsible for managing shared resources entered crisis and conflict. New public and private interests emerged rapidly from the 19th century onwards, driven by increased population, overexploitation, and natural resource degradation. Thus, most natural forest ecosystems in these countries were degraded due to overuse, intensified agricultural and forestry practices, industrial development, and urbanization. Only a tiny proportion of these are semi-natural forests (Jeanrenaud[601], 2001).

These type of problems affecting the community lands was generalized in most of the Mediterranean countries, as is documented in Spain with the "egidos" of Andalusia, Extremadura and Catalonia, in Greece with the "ageladas" and "koinonia ", and Balkans, in Turkey with its "mülkiyeti müsterek arazi" or the "terres collectives" in Morocco and Algeria or "biens communaux" in Tunisia where profound social changes for centuries, the monetization of the economy and the reduction of social cohesion have profoundly changed the forms of land exploitation and led to profound changes in land tenure systems. In the territories of North Africa, the colonial period and post-independence land reforms, which led to extensive privatization or state ownership of land, left communal lands in a residual situation cantoned in remote locations.

Historical and socioeconomic contexts that occur in several world geographies gave rise to new legislation redefining the rights of the State and the duties of individuals. Given its critical role in countries, the State has intervened particularly in land and water resources. Studies on the development and social changes have shown that the processes of change that promote conversion in values are often accompanied by conflict, as there are always several actors involved, such as in this case, farmers, foresters, charcoal makers and traditional shepherds,

[601] Jeanrenaud, S. (2001) - *Communities and Forest Management in Western Europe, Europe*. Gland & Cambridge.

among others, each with different and rarely convergent interests over the same land whose resources were progressively scarcer.

Since prehistoric times, forest spaces in Portugal have not escaped this cycle of impoverishment and vicissitudes as they have been gradually devastated by the axe or the plough and fire. Pavari[602] (1954), referring to the profound millennial intervention of Man in the Mediterranean, writes that "*the predominance of pastoralism in the economy of primitive Mediterranean peoples [...] and its consequences have been more disastrous than anywhere else, [...] a since [...] the three factors of forest destruction, that is, cutting, grazing and fire, have the most intense effects in this specific physical environment*". The situation was no different in Portugal, and the first reference to forest fires in Portugal dates back to the twelfth century (Paiva[603], 1987).

State involvement in forestry is historically connected to Crown land ownership, the feudal tenure system, and its economic and technical characteristics. At the beginning of the nineteenth century when José Bonfácio de Andrade e Silva returned to Portugal after his forest education in Germany, he pledged the need for reforestation and better protection and management of existing forests. Although the strategy proposed by Andrade e Silva to improve the degraded state of the Portuguese forests based on the creation and reorganization of the administration of the King's forests had not been executed, it directly influenced the evolution of the Portuguese public forest administration.

To a certain extent, after the separation of the king´s household and the state, the creation of a State Forest Service and public forest heritage seems connected to the size of the estate inherited from the Crown. In France, for example, about 2,000,000 ha were royal domain (4 % of the country´s present area); in Holland, 13,000 ha (0.3%); in Britain, the crown estates that constitute the de core of the Forest Commission covered only 49,000 ha (0.2%); in Portugal, the original area was 15,000 ha (0.2% of the country's present area) which was the area that had survived the dissolution of game reserves (coutadas) and royal forests.

The fact that Portugal, with a small forestry heritage, created a Forestry Service long before the Netherlands and many other European countries shows that the timing of its creation depended heavily on the needs of internal policies aimed at exercising political and administrative control more effectively over vast territories in interior regions of the country. These policies gave relevance to the urgency of intervention to increase agricultural production and contain intense erosion in some river basins, mainly in the north and centre of the country, minimizing abandoned areas and improving the supply of wood for construction. The reports by Balbi (1822) and Brotero (1827) transcribed by Radich[604] and Alves (2000) paint an excellent portrait of the country's abandonment: "*excluding the provinces of Minho, Trás-os-Montes and Beira, the entire rest of the country was uncultivated, specifying that "almost all the mountains are devoid of trees and with crowns full of heather, gorse, ...*". Thus, it is not surprising that, around 1868, the Portuguese government became intensely aware of the level of degradation of its forests, which at that date reached a shallow area of 7% of the continental territory, and the need to contain intense erosion and damage caused by floods, undertaking the country's reforestation/afforestation initiative.

Furthermore, the country was struggling with a strong dependence on imports of raw wood and paper, further accentuating its already negative trade balance and overcoming the prolonged

[602] Pavari, A. (1954) - *Fundamentos ecológicos e técnicos da silvicultura nos países mediterrâneos*. Estudos e Informação. Trad. Port. Publ. em 1958, DGSF.

[603] Paiva, J., (1987) - A evolução do ambiente florestal em Portugal, *I Congresso Luso-Galego de Conservação e Ambiente, Braga, Outubro de 1987, pp. 76-80.*

[604] Radich, Maria C. Monteriro Alves, A.A (2000) – *Dois Séculos da Floresta em Portugal*, ed. Celpa, 226 pp.

economic crisis that the Portuguese economy had suffered for around two hundred years. In 1822, Portugal lost its main overseas territory, Brazil. The transition from absolutism to a parliamentary monarchy involved a devastating Civil War of 1828-34. Except for the governments of Fontes Pereira de Melo in the 1860s, the constitutional monarchy generally failed to industrialize and modernize the country. At the beginning of the 20th century, Portugal had a GDP per capita of 40% of the Western European average and an illiteracy rate of 74%. Portuguese territorial claims in Africa strongly challenged the country's government and the already reduced public finances. Political chaos and economic problems persisted from the last years of the monarchy until the first Republic of 1910 – 1926.

To understand the deep crisis the country was in and the urgency of finding new economic policies to relaunch the economy, we think it is enough to say that by 1850, per capita income at real prices was not significantly different from what it had been at the beginning of 1530 (Henriques[605], Reis and Palma, 2019).

The advancement of forestry science at that time made available the technology needed to plant or seed forests in areas stripped of vegetation. The political objectives allowed for the expansion of the state bureaucracy that reinforced the presence and power of the State over the countryside, allowing its ability to actively intervene in land use in remote corners of the country.

Under the provision of the territorial reorganization of the Forest Services (Law of 25 November 1886) and considering the level of deforestation reached, the State declared that it would undertake the afforestation of the baldios and private lands whenever it is needed to safeguard public interest and goods: "*successively and partially be submitted to forest regime, …, the uncultivated lands on the tops and slopes of the mountains, the shifting sand of the coastal dunes, and any other piece of which afforestation is necessary for the general interest of the country, in particular concerning the water regime. The terrains … that do not belong to the State will be acquired by expropriation for public utility*". Later (1901), under the provision of this law, the Gerêz and Estrela mountains were submitted to the forestry regime, and reforestation actions were directed predominantly to communal lands.

Forestry is not a transient activity but a long-term project that requires continuous intervention and monitoring. The reorganisation of the Forest Service (1868) implied the installation of technicians and forest guards who would take care of the trees, supervise their development, management and cutting, and advise on land use that best met the regional and local demands. Thus, we can say that the expansion of state power was closely linked to the development of forest services, which occurred in a significant part of Europe (Brouwer[606], 1995). This reorganisation was instrumental for greater involvement of the public administration in remote areas where the State was almost absent and where the degradation of the natural resources was strongly accentuated.

To complete the social environment at the onset of the baldios afforestation interventions, it should also be mentioned that the liberal revolution in 1820, driven by a powerful rural bourgeoisie that yearned for new forms of the revitalization of territories, allied to the gradual insertion of agriculture in the market relations, reinforced the ideas of reterritorialization of peripheral areas by the State, and the expansion of its authority as the only legitimate entity to manage the territory. This movement was already manifest in Europe due to the growing

[605] Henriques, António, Reis, J., and Palma, N. (2019) – The Economic Growth in Portugal from the Reconquista to the Present. Unpublish work.

[606] Brouwer, A. R. (1995) – *Planting Power. The Afforestation of the Commons and the State Formation in Portugal.* NWO. 387 pp.

industrialization and monetarization of the economy, gradually widening social conflict between traditional subsisting economies and communal lands. Tendencies to divide fields into small plots increased as pressure to intensify agriculture was felt, a trend observed throughout history, as Berkes[607] (1989) states. Indeed, in modern Western economies, it was taken for granted that the consolidation of private property rights in the land system, even on small parcels, gave landowners incentives to use land efficiently and invest in land conservation and improvement. No information suggests that this type of trend was different in Portugal. It was also believed that communal property, for the most part, could not provide a more intensive use of land. In this context, it was assumed that the State was not yet prepared or did not have the competence to create innovative institutions that would introduce new rural dynamics outside the canons of the time, and thus considered that private property was the best solution to resolve these issues.

Despite references from Baptista[608] (2010), saying that the baldios administration system since the 15th century ensured the sustainable use of goods and products, avoiding overuse, other sources and reports confirm that the high presence of baldios was associated with unsustainable agriculture practices, overgrazing, intensive charcoal production, and improper logging for selling, aggravating the deforestation in mountainous areas. (Rego[609], 2001). Other authors corroborate the widespread existence of predatory practices - frequent burning for the regeneration of pastures and the intense manufacture of charcoal - practices that were not sustainable and could not bring the accrued agricultural yield needed for the country. Orlando Ribeiro[610] (1963), among others, within the scope of a Mediterranean characterization of our country, wrote, "[...] *Man has also lived alongside this ancient flora for a long time, with fires, ploughings, crops and herds. The degradation it caused [...] is an idea inseparable from the study of Mediterranean vegetation*".

So, not surprisingly, from the second half of the 18th century, the baldio systems began to be the target of successive protests since they started to be seen as retrograde and an obstacle to progress in agriculture and the economy in a country suffering from a long and heavy economic crisis. It is also good not to forget that generalised data available at the world level almost invariably shows that the cure for widespread degradation, as has been reached in Portugal at that time, comprised land reform, property entitlement, fair income distribution and industrialisation without forgetting the issues concerning the nature of public institutions.

It is also necessary to consider the extensive lack of information on Portuguese land ownership dating back to the 16th century. The high degree of allocation of the national territory to feudal lords, ecclesiastical institutions, hospitals, charitable institutions, and educational institutions, such as the University of Coimbra, where their exploitation was based on contracts of various types, e.g. contracts of an emphyteutic nature and leases and partnerships that formed a complex network of obligations towards the owners. Thus, in Portugal, the liquidation of feudalism, the suppression of charters with the Marquis of Pombal, and especially with the liberal revolution left a significant legal void in terms of ownership of land property. Despite this legal inertia, populations living in rural areas and exploiting the land continued to do so. Even in the 20th century, the distribution of rights to use shared resources and their control by communities was

---

607 Berkes, Fikret (1989) – Cooperation from the Perspective of Human Ecology: 70-88, in: Common Property Resources. Ecology and Community-Based Sustainable Development, ed. Fikret Berkes, Belhaven Press, 302 pp.

608 Baptista, F. (2010) - O espaço rural: declínio da agricultura, 1ª ed. Lisboa.

609 Rego, F. (2001) – Florestas Públicas. MADRP, DGF CNEFF.

610 Ribeiro, Orlando (1963) – Portugal, o Mediterrâneo e o Atlântico: Esboço de Relações Geográficas. Lisboa, Sá da Costa, 190 pp.

insufficiently documented to justify property titles. It is no coincidence that, to date, the ICNF (2021) estimates that 20% of the land area north of the Tagus still has no known owner.

At the dawn of the 19th century, political forces at the time considered that maintaining unproductive and communal land, degraded and with low productivity, was a remnant of the feudal regime to be abolished, with a prevalence of the advocation of conversion of communal areas into private property. Thus, at the turn of the 19th century, this conviction of the national need for more intensive use of the soil expressed, for example, in the "Memórias de Economia da Academia das Sciences" of Lisbon (in Hespanha[611], 2018), implied that it was the individual property that best responded to this desideratum. The Portuguese liberal revolution of 1820, like the broad liberal movement across Europe, gave new impetus to privatization by identifying the communal agro-pastoral system as backwardness and an impediment to the progress of agriculture.

So, in the 19th century and under the liberal policy, where common lands were presented as a cause of economic and social backwardness, this process was very marked. Privatization was presented as a sign of progress. And this vision led to the practical extinction of the common areas in the south and the north of the country. The First Republic, already in the dawn of the 20th century, even in the face of protest demonstrations by various rural communities that demanded the return of former communal areas to their status of free access by residents, maintained this orientation and repressed them by force.

If, even in recent centuries, the titling and legal codification of communal lands were already controversial, it is not surprising that the hasty return of land to rural populations under the new Baldio law promulgated in 1976, with institutional and inadequate financial support has helped to maintain the controversy over the issue of communal lands. This controversy concerns not only the use of the territory but also the equal rights of small farmers in the same regions or the benefits and tax exemptions that current commoners enjoy compared to other inhabitants outside the scope of the Baldios.

As Harari[612] (2018) says, human beings think through narratives and not through facts, numbers, or equations, and the simpler the narrative, the better. It is not surprising, therefore, that the narrative of afforestation in Portugal at the end of the 19th century and the first decades of the 20th century, which was always associated with communal areas and their afforestation, has been identified by some authors as a strong driver of impoverishment and the departure of many small farmers from those areas. Furthermore, afforestation is almost always accompanied by the narrative of farmers being dispossessed of their land where the Forestry Services intervened. And so, some poorly conducted actions and trampling became the dominant element in the narrative of afforestation at the end of the 19th century and in several decades of the 20th century, with afforestation and the activity of the Forestry Services presented as having provided a disservice to the communities. Therefore, in the context of this work, it seemed reasonable to us, without going into details that would go beyond its scope, to present the facts surrounding the intervention of the Forestry Services and try to answer whether, in the economic and social context at the time, it was the Forestry Services that were the real drivers of social turbulence around communal goods? Was the creation of the Forestry Services and its intervention in forestry the cause of all the upheaval in rural areas?

---

[611] Hespanha, P. (2018) – *O Papel dos Baldios na Revitalização das Comunidades Rurai*s, 337-360. in: F. Gravidão, L. Cunha, Paula Santana, N. Santos (eds), *Espaços e Tempos em Geografia. Homenagem a António Gama*. Coimbra University Press.

[612] Harari, Yuval N. (2018) – 21 Lessons for the 21st Century, Jonathan Quinn UK, 416 pp.

To answer these questions, we will begin by noting that since traditional management systems invariably involve social institutions as an integral part of their process, most writings on the subject have been done by social scientists, especially geographers (Klee[613], 1980) and anthropologists (McCay[614] and Acheson, 1987). However, the issue of communal lands is not the exclusive domain of any scientific discipline, so its study requires an interdisciplinary approach, transversal to different scientific areas. For example, studies of Portuguese Baldios concerning the nature of property systems as a product of centuries of economic, social, political, and legal changes seem to be missing, despite recognizing the informative wealth of the works of Baptista[615] (2010), Kolos[616] (2020) and Skulska[617] et al. (2019).

As rightly mentioned by Berkes[618] and Farvar (1989) "*The economist studying communal resource-management systems might concentrate on how joint control saves scarce resources, as compared to state management or individual control. The sociologist might suggest that communal organization has to do with group cohesion. The anthropologist might relate resource-management practice to the maintenance of culture and values in that society. The political scientist may emphasize the importance of the institutions in the success or failure of the resource management. The planner may be interested in the ability of local communities to participate effectively in development decisions. The ecologist would look for the long-term survival value of traditional management and how local knowledge of the resources translates into management strategies that make ecological sense. All the above are important perspectives; complementary rather done alternative views*".

Considerable criticism directed to the Forestry Services and the forestry work carried out in extensively degraded areas, supposedly considered a critical driver of the impoverishment of the populations in the intervened regions, is biased by inaccurate assumptions. Indeed, these are often contaminated by opinions, political options, and incorrect generalizations of misdeeds committed by some agents of the forest administration, obscuring the narrative of the intervention of the Forestry Services in terms of the development and safeguarding of the public goods generated. The social, political, economic, and sociological contexts of the times of the forest service intervention are generally forgotten, as well as the urgency to recapitalize and repopulate the interior territory, which remains unresolved.

It is a recognized fact that, throughout history, contradictory interventions into land rights systems by outsiders or the failure to establish legitimate and well-endowed institutions in the face of the growing needs of the population and the appreciation of land values have tended to exclude people with lower incomes and less representativeness. For these people, accessing land and property is further aggravated by creating institutions with parallel or overlapping mandates. The liberal regime and the First Republic were not prepared to guarantee minimum standards for the rapid resolution of conflicts nor the dispensation of justice, accountability and transparency in the management and access to land, avoiding false declarations of rights or land usurpations. Adequate information on alternative ways of conciliation of agriculture

---

[613] Klee, G.A., ed. (1980) – World Systems of Traditional Resource Management, Wiston, NY

[614] McCay, B. J. and Acheson, J.M., eds., (1987) – The Question of Commons, University of Arizona Press, Tucson

[615] Baptista, Fernando (2010) - *O Espaço Rural. Declínio da Agricultura.* Oeiras: Celta. 213 pp.

[616] Kolos, I. S (2020) – *Governance of Community Forest Areas in Mainland Portugal Over the Last 40 Years: Results, Current Trends and Future Perspectives*. Doctor Degree Thesis, Universidade de Lisboa, 400 pp.

[617] Skulska, I., Colaço, M.C., Monteiro, M., Rego, F.C., 2017. Report of CEABN. Assessment of Community Based Forestry with FAO methodology. Instituto Superior de Agronomia. Unpublished work.

[618] Berkes, F. and Farvar, M.T (1989) – Introduction and overview, 1-17, 1n: F. Berkes (ed), Common Property Resources. Ecology Community-Based Sustainable Development, Publ. in Association with The International Union for the Conservation of Nature and Natural Resources, 302 pp.

development and environmental protection at the lowest costs (economically and sociologically) was absent in the policy instruments promulgated. The most violent demonstrations against the Forest Service occurred when state interventions were initiated in common areas during the liberal regime and the First Republic (Louro[619] , 2016). However, the truth is that this resistance and revolt of the populations in the last decade of the 19th century to the first land interventions predates the existence of the Forest Services. It was found that in most cases, the populations of the intervention areas were not supported by new legal instruments that facilitated the transition to new forms of land use, without which commoners did not feel the resolution of issues of equitable access to resources or the benefits of the development.

In many cases, aggravating population malaises were the tax increases imposed by the Parish Councils or the slowly successive appropriations resulting in privatization/intervention of the "baldios", whether internal or driven frequently by outside individuals misleadingly becoming private owners or by municipalities. These appropriations had nothing to do with issues of afforestation.

The afforestation, so to speak, is the scapegoat of an already installed malaise reflecting the population's impoverishment, the depletion of natural resources and the absence of appropriate institutions.

Another source of misunderstandings and source for political disputes was the imprecise definition of what that entity called Baldios was. This clarification is essential to minimize the fluctuation of our legislation and the instability of the institutions that oversee agriculture and forestry. So, at that time, what was the understanding of what was called Baldios? In the Portuguese lexicon, baldio corresponded to uncultivated or wild land, also called "*terra maninha*" [useless land]. As early as 1869, the designation of the universe classified as "Baldios" was applied in the sense of "free space" and referred to as "*logradoro comum*" [communal areas] for those *lands effectively used for agriculture, pastures, woods, firewood, etc., by local populations*.

This is how, in 1869, a new law was promoted that intended to subject the Baldios to disentitling policies - which had been applied to national heritage (1834), church properties and "dead hand" institutions (1861 and 1866) - preserving only those that communities have revealed to be essential for daily use. The strong popular reaction against this threat of appropriation of common lands prevented the widespread application of this law. Later, in 1893, it was the positivist idea of bringing progress to agriculture that inspired a new wave of legislation against communal lands, this time to promote the colonization of uncultivated and communal lands by landless peasants, hoping that, in the words of Acedo[620] (2021), would increase food production for the market. In this context, the first goal set by the Forest Service was the afforestation of Gerês and Estrela mountains, which were mostly *Baldios*.

The disentitling of Baldios, their division and individual appropriation to convert uncultivated land into cultivated one were particularly accentuated from 1869 onwards. This disentitling policy was directed towards uncultivated areas, not individually or community appropriated. From here, the afforestation of the mountain wastelands has intensified since 1888 and gained momentum from 1903 onwards. It, therefore, seems clear that at the time, there was a clear distinction about the occupation of space: the open and uncultivated land (baldio) and the communal land where effective use of space operated. Only later did the expression "Baldio"

[619] Louro, Victor (2016) - *A Floresta em Portugal. Um Apelo à Inquietação Cívica*. Lisboa, Gradiva, 268 pp.

[620] Acedo, Sara S. (2021) – Os baldios e as Práticas Comunitárias em Portugal. Relatoria del I Seminário Permanente ECOEMBEDDEDNESS (29/1(21), 10 pp.

come to have a broader scope, and this distinction fundamentally disappeared after the "Communal land" devolution law in 1976.

This understanding of the concept of common property (*res communis*), that as we said is distinct of open access (*res nullius*), is well established in the Anglo-Saxon law and the Roman Law that have had a critical influence in the Portuguese jurisprudence. In the words of Bromley[621] (1985) "*the mischief from the term of 'common property' is that many …. do not understand the critical distinction between 'open-access' (res nullius) and 'common property' (res communes). Open-access resources is a free for all, while common property represents a well-defined set of institutional arrangements concerning who may make use of the resource, who may not make use of a resource, and rules governing how the accepted users shall conduct themselves and how they are transmitted*".

The distinction between the two concepts is crucially important with regard to the better understanding the evolution of the "baldios" in Portugal and also to understand their dynamics with regard to the "tragedy of the commons' model of Hardin[622] (1968) which guides the thinking of many resource managers. According to Hardin's model, such resources held in common are doomed to overexploitation since each resource-user places immediate self-interest above community interest, concluding that resources should either be privatized or controlled by a central authority to ensure sustained use. Higher market integration and monetarisation of the economy tended to accentuate pressures on the resources.

The term "common property" has been used interchangeably for communal land and uncultivated fields. However, the critical distinction between "open access resources (*res nullius)* and true "common property" (*res communes*) was clearly expressed in the Portuguese Civil Code in the 1940s. This differentiation presupposed that there should be sociological relations and a degree of cohesion and solidarity between partners in regulating the power of arbitration and in exploiting community resources, conditions that were often forgotten. During the inventory of Baldios, the imprecise interpretation of the Civil Code and the instability of the institutions that oversee agriculture and forestry were sources of important errors in recognizing free land (Baldio) and common areas. It integrated common lands into the property of municipalities and parishes, defining them as "*common things", that is, not individually appropriate, from which it is only allowed to take advantage [...] of individuals included in certain administrative circumscriptions*".

In Portuguese's case, we think it also fair to say, as Berkes[623] (1989) mentioned, that the use of the term "common property" has been partially controversial and, in several cases, misused because of differences in the philosophical basis of traditional views as opposed to Western scientific resources management. A contemporary view holds that property is either private or belongs to the state. In this view, resources not subject to ownership are open spaces, representing a free good (not owned by anyone). If it were a common property, it should be restricted to communally owned resources, managed according to communal arrangements to exclude non-owners and for allocation among co-owners. The concept implies that the potential resource users who are not members of a group of co-equal owners are banned. The idea of communal property or private has no meaning without this feature (Ciriacy-Wantrup[624] and Bishop, 1975).

---

[621] Bromley, D. W. (1985) – Common property issues in international development. *Developments*, 5(1): 12-15

[622] Hardin, G. (1968) - The tragedy of the commons. *Science* 162:1243-1248.

[623] Berkes, Fikret (1989) – *Common Property Resources*. Ecology and Community-Based Sustainable Development. Belhaven Press, 302 pp.

[624] Ciriacy-Wantrup, S.V. & Bishop, R.C. (1975) - Common Property as a Concept in Natural Resources Policy, 15 *Nat. Resources J.* 713

We believe it is worth mentioning that, even before the Liberal Revolution, the Municipalities held a significant land patrimony, made up of cultivated areas (under lease) and uncultivated land used by the population in an accessible way, often confusing the intentional relationship between communities and the parish councils' heritage. In the historical process of attributing the national territory to feudal lords and their descendants, the customs of access for collecting firewood and some grazing were almost always maintained as long as they did not affect the hunting population. This customary land access to some resources could hardly be understood as a hereditary and transmissible right or co-ownership since it is characterized by communal property (res communes). This uncertainty about the lack of explicit allocative rights of use and ownership, in conjunction with the incredible freedom of interpretation in which our law is often applied, has given rise to lawsuits and abuses over land grabbing.

In the south and southeast of Portugal, the close-up land movement caused the absorption of small farms, which were already a minority in these regions, and consolidated the large estates. The process of liquidation of feudalism in Portugal, guided by the Liberal Revolution, greatly increased State ownership, namely forestry estates, but shortly after, these were transferred to private and successively divided.

In this historical process, the forests were left out, remaining in the hands of traditional feudal lords or their successors, owing the right to cut the trees under a mine type operation. In these forest lands the populations collected firewood and grazed the cattle, following the customary rights.

In the 19th century, the emergence of a profitable market for cork stoppers and charcoal, led to the expansion of lands occupied by cork oaks and holm oaks, subject to a mine exploitation. In this context, an absence, or a loose set of imprecise property rights, means that no actor can prevent others from accessing the future resources. Under this conditions, too many people using a resource leads to an inefficient utilization and to a particular propensity to overuse of resources. Therefore, the social optimum occurs at a lower level of use of the resource considered, by comparison with the supposedly theoretical economic optimum.

In fact, in the absence of a central decision-maker or the lack of clarity of access rights, the individual appropriation of goods extracted from a shared resource, e. g. a forest or a pasture, also conducts to inefficient low level of use. Every time there is a specific appropriation of a common resource, an externality cost arises affecting all users, since fewer resources will be available to all. This cost is generated by the effort allocated by every member to exploit the resource.

In the absence of a mechanism to balance social benefits and costs, there is an incentive for people to overuse a given common resource, particularly in the preliminary phases of market integration and monetarization of the subsistent economies. In practice, as there are no costs, except those referring to externalities, the described trend to overuse leads, in the limits, to the practical exhaustion of the shared resource. The history of unrestricted access to land and forest assets perhaps explains a little, in the words of Louro (2016), "*the attitude of current owners, many of them descendants of people who received them without great effort and also used them without great effort*".

History shows that in traditional rural communities, contradictory interventions in land rights by authorities or the inability to establish legitimate institutions in the face of pressure and the growing needs of the population lead to an appreciation of land values that tend to exclude the poor access to land ownership, eventually resulting in the creation of parallel or overlapping institutions. Imprecise understanding regarding free use and true communal land was a tremendous source of misunderstanding, conflict, and fertile ground for political struggle. The unclear terminology, embraced with epistemological naivety and strong prejudices by researchers, did not contribute to analysing the results of the economic and social efficiency of forestry policies from 1886 onwards.

Can this imprecision and lack of a central mediator on land use explain Portugal's near depletion of wood resources in the 19th century? Wasn't the State's intervention to safeguard the common good induced by the absence of local communal mechanisms that regulated the allocation of resources and the necessary investments for their maintenance? Was it not the depletion of resources that was the leading cause of the impoverishment of an already seriously disadvantaged population and not the afforestation interventions that undeniably brought tangible benefits in terms of physical access to markets and job creation in the intervened regions?

In this process, and regardless of the technical component of afforestation, it must be considered that the slowness and inefficiency of interventions by courts and territorial bodies, as well as the lack of human preparation of forestry agents on the ground, did not allow the population's apprehensions to be appeased nor did they facilitate corrective measures. Here, a clear gap in the institutional structure of the Forestry Services regarding the sociological component necessary for the inclusion and active participation of the population in the intervention areas is worth mentioning. Even today, the guarantee of minimum standards for the rapid resolution of conflicts and for the administration of justice to deal with issues of land repossession in 1976 has not yet materialized. Likewise, mechanisms safeguarding accountability and transparency in management and access to land have yet to be implemented 47 years after the land was returned.

The execution of the country's afforestation under the forestry regime concerning the organization of forest management, rural infrastructure construction, policing, and other ordinances were regulated by the laws of 1901, 1903 and 1905. The relevance of the definition of the forestry regime was that the State no longer needed to expropriate the areas it wanted to afforest. In this way, the State created the legal conditions to intervene in land areas, whether public or private, whenever it was understood to be pertinent to safeguarding the interests of the public goods. Only in the event of the landowner's refusal to accept submission to the Forest Service's intervention could the State proceed with expropriation.

Since 1925, all matters related to common areas were centred on the “Division of Common Areas” to coordinate intervention measures and the policy for converting the remaining communal areas. The dominant concern was not to leave the land unused to combat the intense crisis of food subsistence in which the country was living.

Despite the criticism, we can say that it was thanks to the efforts of the Portuguese Forestry Authorities at the time and the recognition of the need for a coordinated operational structure equipped with specialized personnel that made possible the successful recovery of the Portuguese forest area, which from 1880 to 1934 went from 7% coverage for 28.3% (2,520,000 ha) of Portuguese territory.

In 1932, decree 20 523, on the initiative of the Division of Baldios, Uncultivated and Colonization of the General Directorate of Agricultural Social Action of the Ministry of Agriculture, mentioned that:

> "*There are still extensive areas of vacant land susceptible of a remunerative exploration; It is not possible to proceed from now on with the registration of the baldio lands existing in the country, as determined by article 26, line a) of Decree no. 20 523 of December 1931; but, the need to make an immediate inventory of them becomes imperative as preliminary work for future registration [...]*

By what is decreed:

Article 1. City councils and parish councils are obliged to send, within sixty days from the publication of this decree to the Directorate-General for Agrarian Social Action (Division of Baldios, Uncultivated and Colonization) a list of existing vacant lands, whether they are or not used as common land".

Although 46 Municipal Councils and 724 Parish Councils did not send information on time, records revealed that the identified Baldio area represented 140,000 ha (Decree 22 390). Six years later (1938), the Internal Colonization Board reported the allocation of 347,252 ha of wasteland for forestry on the mainland and 57,000 ha on the islands. The area discrepancy is abysmal. This was fundamentally due to the lack of a clear understanding between baldio (uncultivated land) and community land. A new decree ordered the General Directorate of Agrarian Social Action to proceed with the immediate survey of communal assets. Priority was given to studies to recognize the perimeters of the river basins of the Mondego, Ponsul and Liz rivers, where erosion was accentuated, the Alcoa and Sado rivers and the Sacavém, Ota, Alenquer, Muge and Salvaterra rivers.

It was then recognized that it was essential to improve understanding of property rights, their evolution over time, and how they affected household behaviour. Awareness was gained that this clarification was important from the point of view of formulating policies and government intervention options to avoid negative impacts from resource degradation social upheavals or to increase returns on investments in more intensive use of land or better protection of natural resources likely to influence population growth or opportunities generated by technical and market advances.

Thus, this recognition in 1936 of the importance of administrative codification of property rights and what common goods were from a legal point of view led to a global review of those issues. Thus, the new Administrative Code dedicates a single chapter, Title VI, where Baldios areas are classified into Municipal and Parish. As for their social utility and agricultural aptitude, the Baldios areas were classified into groups: 1) indispensable or dispensable to the community public use. The latter was, in turn, divided into two groups: 1) suitable for culture and 2) unsuitable. Finally, another distinct group differentiates those planted with trees or intended for afforestation.

In the review of the Administrative Code in 1940 by Prof. Marcelo Caetano, it was stated that the baldio is constituted by the component of common land (inalienable goods, heritage of successive generations, protection from poverty and comfort for all) and in which only specific and determined people can take advantage, limiting the administrative authorities to the mere policing of these activities. This review also considered the assets of the parishes and municipalities, constituting their heritage or private domain, which are public assets that satisfy collective needs that the State or the autarchy's function is to provide.

So, the distinction between baldio and communal land remained. The "Estado Novo" continued its intervention on the Baldios and community lands. Still, progressively, also because it had at its disposal new knowledge and different perspectives on the organization of the territory and the land use capabilities, it softened the previous policy and diversified its destinations: "*Some land will be planted with trees, others will serve as a common heritage for the local people and others can and should be used for colonization*".

The need to repopulate the interior and to reconstitute the territory's natural resources and the associated bottlenecks to reduce the country's dependence on food led the government in 1936 to create a body, *Junta de Colonização Interna* [Internal Colonization Board], under the responsibility of the Ministry of Agriculture, entrusted with taking care of the land assigned to it by the Autonomous Board of Agricultural Hydraulic Works, installing agricultural farms on them; promoting the formation of associations and irrigators and the installation of Agrarian Posts; carrying out the recognition of the physical and socio-economic characteristics of the interior regions of the country and establishing the reserve of vacant lands of the State; proceed with the acquisition of land for colonization; study the legal regime to which the concession of land should obey..

It seems clear that both in the letter of the law and the legislator's mind, the component referring to what is classified as communal land would continue to have the same destination (*inalienable assets, heritage of successive generations, protection against poverty and comfort for all*). It was up to the administrative bodies and the Internal Colonization Board [JCI] to decide which lands would be unnecessary for local communities. The decommissioning of community fields in favour of JCI required the consent of at least two-thirds of the heads of families who used them or proved that the areas had been abandoned for more than ten years or that only isolated acts of exploitation had occurred. Land removed from the community area suitable for cultivation and not reserved by JCI would be divided into lots of at least 1 ha to be rented or sold at public auction to heads of families previously co-owners in their use.

The Government was entrusted with producing the regulations necessary for the division, preferences, tenure conditions, remission of jurisdiction or conditions of sale if sold. However, as long as these regulations were not published, the administrative bodies could lease the vacant lots in question for a period not exceeding six years. Districts with "Baldios capable of afforestation" were obliged to promote the respective afforestation by their budget or in co-payment with the State within twenty years and according to the exploitation plan drawn up by the Ministry of Agriculture. The lands afforested in baldios would be subject to the Forestry Regime.

The times of participatory approaches, now considered essential in designing forestry intervention projects, were still far off. It should be noted, however, that this pioneering objective of peoples' participation appears clear in Law No. 1971 on Forestry Regime of 1938, as it expresses in its article (Base IV) "*the aim to promote, as much as possible, the conciliation of the well-being of the Baldios people with the general interests of afforestation and ordered that the conclusions of the surveys of economic and social characterization of the peoples of the Baldios be put to popular auscultation" (Base V). The Law also provided that the submission decrees should establish "whenever circumstances permit*", the conditions under which the interested people could continue enjoying their previous benefits.

Despite this flexibility in the legal provisions, over the years, we have seen some pockets of resistance and opposition that must be attributed to arbitrary field interventions due to the lack of sociological preparation of the intervening field professionals and the lack of human sensitivity of some agents of the forestry administration regarding the way to deal with the population. Policies and instruments to accommodate people's participation in land management were still unknown worldwide.

The slow increase in wooded community areas, which had been mainly left to the local authorities, pressured the State to enact in 1938 the "*Plano de Arborização dos Baldios Norte do Rio Tejo* [*Afforestation Plan for Baldios Norte of Tagus River*]", also known as the "Lei dos Baldios [Baldios Law]", which was the main instrument of support for afforestation and a significant boost to the development of these areas. The defined goals included the afforestation of 420,000 ha of uncultivated land, the installation of 33,000 ha of reserves, and 60,000 ha of pasture. The plan contained a detailed timetable, a summary of the necessary financial means and an estimate of its economic results in social and economic terms. It also included plans for infrastructure works to serve the newly forested lands and assist the mobility of populations in neighbouring villages (the construction of 25,000 km of roads and over 5,000 km of telephone networks). So, the Afforestation Development Plan brought about a significant and rapid expansion of the area controlled by the Forest Service. In fifty years, between 1888 and 1939, 76,000 ha were submitted to this regime, and in the following twenty years, 383,000 ha (Mendonça[625], 1961).

Since land classified for afforestation/reforestation was considered unfit for agriculture according to international cultural standards and outside the legal definition of communally owned land (restricted to lands and resources for which formal community agreements exist to exclude non-owners and for their distribution among co-owners or tenants), the narrative that afforestation has driven the population into poverty seems to need a better and more comprehensive explanation.

Given that the interventions of the Forest Services were generally accompanied by the improvement of access, mobility, and other services, we rarely find information on how those populations developed and the consequences of their increased participation in the market economy and its decrease in dependence on subsistence agriculture. In fact, and as far as it was possible to investigate, the following probative indicators used to assess the functioning of the social structure of communities in most conflicting areas of forest intervention are rarely documented:

1 - The level of disputes and the effort that the community expends to maintain the rules for managing and enjoying the goods produced (efficiency measure);

2 - Capacity to face the progressive changes resulting from the increase in pressure and the decrease in social cohesion (stability measure);

3 - The ability to accommodate sudden changes or pressures (resilience measure);

4 - The perception that the members of the group have, regarding the fairness of the sharing of benefits and burdens among themselves (a measure of equity).

Questions about what bundle of rights (specifically the right to manage and alienate the common-pool resource) provides the necessary incentives for co-owners to invest resources to prevent common-pool resource overuse and who defined property rights and allocated them among individuals are also poorly unknown.

In 1954, with the Law 2069, there was a change of emphasis in terms of land to be afforested and whose objective was to enlarge the afforestation efforts to include the private lands without excluding the possibility of continuing its intervention on State land, municipalities, baldios, and public utility institutions. It was recognized that there were extensive areas, mainly south of the Tagus, heavily degraded by interventions in wheat production campaigns on land with poor agricultural capacity, which could be recovered thanks to the potential of forestry. So, various incentives were created for its implementation, such as exemption from property tax and instruments for accessing credit.

Considering the claim that the intervention of the Forestry Services was beyond impoverishment of rural populations, a strong driver of the emigration of rural people from the interior of Portugal, it seems to forget that these areas of the country were already heavily depopulated by emigration, mainly to Brazil, drive out from Portugal by poverty (and not because of the afforestation) and lack of prospects for life improvement. It is no coincidence that

[625] Mendonça, J. da Costa (1961) – *75 Anos de Actividade na Arborização das Serras*. Lisboa. Ministério da Economia, Secretaria de Estado da Agricultura, DGSFA.

in the 18th century, long before the interventions of the Forestry Services, emigration to Brazil, which was already significant, had increased dramatically to such an extent that the Portuguese Crown had to establish barriers to contain emigration. Estimates made so far place the number of Portuguese emigrants in Brazil in the 18th century at 600,000 (Boxer[626], 1969), considered one of the most significant movements of European populations to America during colonial times. This flow to Brazil was practically important until around 1929, coinciding with the world stock market crash (Pasckes[627], 1991).

We must remember that large areas of these degraded lands, with a high representation of low land use capacity for agriculture and in communities without the ability for technological innovation or extension institutions capable of triggering a developmental impulse, did not allow more than a meagre subsistence.

The truth is that degraded soils of mountain areas, with a dry season coincident with high temperatures and irregularities in the climate, did not provide the population with subsistence conditions, much less capital accumulation. Human haemorrhage to other places goes back centuries and still explains the country's demographic performance.

Although the pace of emigration slowed down in the 19th century, it was already substantial with a high representation of peasants from rural areas, with a predominance of people from the provinces of Beira Alta (22.6%), Trás-os-Montes (14.5%), Minho (13%), Beira Litoral (25%), precisely those with the most expressive representation of common areas (Table AI.1).

Observation of the current situation (column 5, Table AI.1) shows that the land returned in some districts differs significantly from the values contained in the official inventories of 1939. The justifications must be the considerable gaps in the land register and the negligent application of the rules that allowed a significant appropriation of the lands after devolution by some *baldios*.

Table AI.1 – Mainland baldios recognized by the *Junta da Colonização Interna* (JCI) [Internal Colonization Council] and current area under Forest Regime

Districts	Baldios recognized by the JCI[628] (1939)			Baldios under Forest Regime in 2013(*) (ha)
	Total area (ha)	Percentage of baldios areas in relation to district areas (ha)	Baldios areas with possible forest use (ha)	
Aveiro	8,761	3.16	8,387	8,600
Beja	7,157	0.70	555	0,000
Braga	6,140	2.25	5,742	41,370
Bragança	25,233	3.86	17,046	52,776
Castelo Branco	13,217	1.97	12,819	14,710
Coimbra	34,241	8.66	30,883	29,600
Évora	940	0.13	358	0,000
Faro	4,245	0.84	242	1,870
Guarda	29,360	5.34	22,596	23,300

[626] Boxer, C.R. (1969) – The Golden Age of Brazil, 1685-1750: Growing Pains of Colonial Society (2nd ed.). Univ. of California Pr. 443 pp.

[627] Pasckes, Maria Luisa N. de Almeida (1991) – Notas sobre os imigrantes portugueses no Brasil (sécs. XIX e XX). Revista de História (123-124): 81-93.

[628] JCI (Junta de Colonização Interna [Internal Colonization Council]. (1939) – Reconhecimento dos Baldios do Continente. Junta de Colonização Interna, Ministério da Agricultura, Lisboa, Vol I and II.

Leiria	19,616	5.71	12,925	5,150
Lisboa	1,226	0.45	1,082	3,900
Portalegre	3,862	0.60	34	430
Porto	2,530	1.11	2,355	6,170
Santarém	14,024	2.10	3,562	12,500
Setúbal	184	0.04	168	0,000
Viana do Castelo	56,588	26.84	49,649	30,350
Vila Real	107,005	25.25	95,468	134,670
Viseu	73,391	14.68	68,497	72,850
TOTAL	407,543		332,366	438,245

(*) Kolos (2020)

Under the troubled narrative of forestation in Portugal at the end of the 19th century and in the first decades of the 20th century, the interventions of the Forestry Services appeared as the culprits for the privatization of land in community areas, identifying it as the decisive driver of the impoverishment of many small farmers in the Baldios areas. It is in this sense that Halpern Pereira (1971), regarding the effect of State forestry intervention on common goods (cited by Louro, 2016), states that the "*suppression of communal rights and common pastures led to the fencing of fields, a legal justification, which did not exist before and which encourages it everywhere, causing the impoverishment of small farmers, who simultaneously lose pastures, wood and vegetable manures*".

The presumption that privatization alone was the driver of impoverishment in the late 19th century and the first decades of the 20th century seems a simplistic explanation because it does not illuminate the accelerated conditions that led to the departure, which were firmly rooted in poverty and lack of development prospects, even before afforestation work. We believe that if we were faced with true communal lands that are presented and defended as examples of social cohesion and a spirit of cooperation and mutual aid, resolving socioeconomic disparities between their members, it does not seem reasonable that these distinctive attributes of the Baldios would not have mitigated the conditions of those left without land.

As for the new landowners, they remained poor, just like their neighbours' commoners, because they could not fully utilize the resources, they now have exclusive rights for other reasons (lack of new technologies and investment capital). Without the appropriate conditions (e.g. new technologies, more productive plants, and new product market solutions), the new owners of resources use them, not increasing their productivity and producing a harvest below what is considered optimal.

So, the narrative on the causes of the increased impoverishment of those populations where small farmers were established in areas of Baldios subject to the forest regime is not as linear as one might imagine. Sociological analyses on the effects of land privatization movements are not enlightening if they ignore the sociological and historical framework at the time of appropriation events and the diversity of relationships involving ownership and access conditions under which resources were held. Some examples in other countries and one or another case in Portugal indicate that in areas with true social cohesion and an effective and resilient communal organization, the local population responded to the external dynamics of land appropriation by adopting flexible forms of property.

It should also be said that the existence of private property within a communal area and extracted from it by force of law, if that was the case, does not necessarily imply the absence of social benefits and mutually beneficial economic relations between the two systems. Despite not being exhaustively studied, this flexibility seems to have only been possible in areas where the social rules and social cohesion characteristic of true commons existed, which we think did not happen in many of the claimed locations. There are authors (e.g. Ribeiro[629], 1970; Rodrigues[630], 1987; Brouwer, 1995) who identify in Portugal and Spain situations that in response to governmental disentitling policies, villagers formally divided their commons into private plots while maintaining in practice the communal use form that the government sought to abolish. Independent of these cases of the strategic response of the commoners to external pressures, private demarcation was not the main driver that accelerated impoverishment or immigration, but rather the fact that these areas could no longer maintain their young population due to the depletion of their resources and lack of life perspectives.

Bearing in mind that the main objective is to find adapted institutional instruments that can face scarcity and conflict, guaranteeing the sustainability of its exploitation and the fair distribution of wealth, the discussion focused exclusively on the ownership status of a resource, leaves unanswered the examination of the diversity of relationships involving ownership and access conditions under which a resource is maintained, which may require a two-dimensional classification of the resource under examination as proposed by Lino Grima[631] and Berkes (1989).

In fact, relations of access to property can be more complicated as we are faced with a continuum of conditions where it is possible to identify more than one set of factors that can lead to the unfeasibility of sustainable exploitation of resources. Although privatization was probably not the only solution, the truth is that when you want to protect land in a phase of severe degradation and to encourage economic growth through the strengthening of a market economy, communal ownership and control are complicated to maintain without mutual coercion, whether through the force of law respecting property rights or community peer pressure enforcing responsible use. It must also be said that, given the cross-cutting nature, far-reaching implications, and often long-term horizon of land policy interventions, effective independent socioeconomic research is still lacking to provide informed insights to policymakers.

It is generally accepted that in cases of resource degradation, ownership helps solve interest conflicts in natural resources management in open access lands and the democratization of this process. Contemporary policy analysis and debates reflect this omnipresence of tenure security for development. Land policies, focusing on legal and institutional aspects, were seen in the 2000s as key for establishing secure property rights (Deininger[632], 2003). Available world knowledge shows that donor programmes in developing countries, where tenure security is taken as a leitmotiv for reforms, have flourished.

Most recently, tenure security, including private and communal land, has been appropriated by international policy frameworks. The Sustainable Development Goals (SDGs) and the Voluntary Guidelines on Responsible Governance of Land and Forest Tenure in the Context of National Food Security refer to it. Particularly in the developing world, a call to secure tenure has been made, whether private or communal rights, for local people to ensure their livelihood opportunities or to scale up land registration programs to protect individual rights, avoiding what is now known as land grabbing by international companies and foreign governments, to reduce the future vulnerability of the rural population.

---

[629] Ribeiro, Orlando (1970) - A Sertã: pequeno centro na área de xisto da Beira Baixa. *Finisterra* vol. V (9): 103-112 [https://doi.org/10.18055/Finis2473]

[630] Rodrigues, M. (1987) – Baldios. Lisboa, Caminho

[631] Grima, A.P., Berkes, F.(1989) – Natural Resources: Access, Rights-to-Use and Management. pp35-54: in: Fikrets Berkes (ed), Common Property Resources. Ecology and Community-Based Sustainable Development. Belhaven Press, 302 pp.

[632] Deininger, Klaus (2003) – Land Policies for Growth and Poverty Reduction. Co-publication of the World Bank and Oxford University Press, 202 pp.

International experience has also shown that the uncertainties and instability inherent to frequent changes in land tenure or natural resource policies make these assets subject to inevitable pressure from opportunists and are mostly condemned to degradation. Unquestionably, in these cases, the natural resources of these lands are the subject of mining exploitation. To worsen this situation, now visible mainly in developing countries in the tropics, population growth has made the product of available household plots increasingly scarce, generating pressure to redefine property rights on land where rights of access and co-management to resources were not transparent or were permissive in terms of responsibility for the management of these lands. This also affects the distribution of the wealth produced, which in these areas was limited to natural products naturally conditioned by their exploitation cycle. In this situation, the institution of small private property was almost always considered adequate to guarantee the fruits of individuals' labour and minimize the degradation of resources. The available international experience also shows that the continued reduction of individual family incomes, even without external interventions on land tenure, inevitably led to a more or less extensive rural exodus.

History has also shown that the evolution of property rights is not an exclusive response of purely economic forces but also, at times, a response needed from the State in fulfilling its obligations to safeguard economic and environmental externalities (reduction of erosion, contribution to water conservation, environmental protection, and biodiversity protection), not appropriated by the market. It is therefore not surprising that the existing arrangements in many countries, and Portugal, are conducive to political controversy and more or less biased ideological interpretations of the goodness of their results from an economic or social point of view.

Although recognizing the importance and social role that today is attributed to communal lands, in the light of new knowledge hitherto unknown at the time of afforestation interventions in former communal lands, it is understood that society and governments must consider at each historical moment the model and means available to respond to the challenges of each era. In the Portuguese case, land protection, faster market integration and increased agricultural productivity were the urgent challenges that motivated interventions in the 19th and 20th centuries. It is, however, doubtful whether the recognition of this importance that inspired its return in 1976, in a different historical and socioeconomic context, was accompanied by the appropriate instruments and supports to achieve the objectives set.

Today, what was not clear at the crucial time of afforestation actions, we can recognize that land interventions required not only technical preparation but also comprehensive social knowledge, including the ability to transmit to the intervened population information about the program and the roles and rights of small farmers and community residents and applicants for land and benefits derived from the program.

The experience available in different geographies shows that the mobilization of the population, its strong commitment to river basin afforestation rehabilitation projects, and a clear understanding of the project, the implementation process as well as the multiple potential benefits that would derive from them are essential conditions for the success of the interventions. The available information also shows that, in addition to mobilization, success in interventions on land tenure was linked to the transversal reorganization of executive services and its training to resolve conflict issues and constraints in previous actions. It must be noted that community organization is not a single, short-term activity, as is practised in most community projects, but rather a long-term process. Training and capacity building are mandatory to improve smallholder farmers' skills and knowledge regarding best practices in implementing watershed or landscape rehabilitation projects. It is also essential that training and capacity-building activities are adapted to the information, skills and knowledge needs of stakeholders. This did not happen between us in the past and is not happening in the present.

Today, it is easy to say that the Portuguese authorities, rather than embracing the historical significance and values embedded within communal ownership lands, could have continued to nurture their unique heritage, and foster a different line of development and action instruments. Instead, the action adopted by Portugal corresponded to the prevailing social and political reading in Europe and the widespread perception that the management of communal lands was depleting even more of what were already degraded natural resources.

So, it does not seem methodologically correct to judge past measures and policies on land use in the light of the dominant knowledge available today, which was strange in the past. Let us not forget that the thought that shapes the new forest intervention policy measures on community lands (Community-Based Forests), whose development dates back to the late1970s and 1980s and whose advocacy is very recent in Portugal, is still awaiting institutional support and a consequent and coherent legal framework to mitigate the evident absence of sustainable forest management and to improve adverse property structure of our woods.

Empirical evidence shows that in the course of development, practically everywhere, the need to sustain population density, which was not the specific case of the intervened baldios, or to take advantage of the economic opportunities associated with trade will require investments in the land that cultivators are more likely to do so if their land rights are guaranteed and where the ability to use the land allows it. Given that we were practically facing developing economies, it would have been necessary to create adequate institutions with an innovative capacity capable of triggering a virtuous circle of economic and population growth that would successively attract more significant investments in technical and human capital, inducers of economic development and well-being. However, these were not the conditions in the areas intervened by the Forestry Services, mainly in mountainous regions and degraded soils, with impoverished rural economies where their investment capacity was not foreseen, and access roads were practically non-existent. Despite these disadvantageous physical conditions and social inertia to change, it was thanks to the resources created and the opening of access roads and communications infrastructure that allowed the conditions for the development of numerous sawmills, the resin distillation industry and the bases for a particle board and paper pulp industry, fundamental for generating economic growth, employment, and a high contribution to the Portuguese trade balance.

To assess the importance of the afforestation carried out in the Baldios at the time, suffice it to say that in 2010, the forest in their possession, without taking into account the goods corresponding to the environmental services generated, provided around 80% of the Economic Total Value (TEV) of direct goods sold by the Baldios reaching to 69.5 million euros/year, that is about 15% of the Portuguese Forestry TEV at that time (AFN, 2010).

Indeed, over the last few decades, the commons have received increased attention from scholars due to their relevance and the problems of overexploitation that have characterized them. Alongside the issues that arose around the Commons (namely the tendency towards its exhaustive exploitation, which, as we mentioned above, led to what Hardin called the tragedy of the commons), it emerged, as discussed by Filipe[633] et al. (2007), a significant concern around a new concept, Anti-Commons, within the scope of the analysis of property rights that may lead to the existence of an excessive partition of property and that also generates problems for society,

---

633 Filipe, José A., Coelho, Manuel Francisco, Ferreira, Manuel A.M. (2007) O Drama dos Recursos Comuns nas Sociedades Actuais. À procura de soluções para os ecossistemas em perigo. Edições Sílabo, LDA., 298 pp

leading to what became known as the tragedy of the Anti-Commons (Heller[634], 1998). Both the Commons and the Anti-Commons are characterized by inefficiency in the use of resources: the first is characterized by over-exploitation and the second by low levels of resource use, in this case, due to the risk of leading to an excessive division of ownership, making the efficient use of the resource too expensive, as happens with forest management if the scale of the management unit does not have a minimum dimension.

In the 1980s, the commons gained new importance and were considered pivotal in social, environmental, and sustainability studies of natural resources. For that reason, since its birth in 1989, the Committee on Human Dimension of Global Change of the National Research Council in the USA has recognised the importance of commons and joint research. Not only is the topic important in its own right, but it is also a central theme in studies of international cooperation, environmental decision-making, and the design of resource management institutions. Almost all environmental issues contain aspects of common goods, namely indirect ones, or externalities (climate change mitigation, erosion, flood containment, etc.). There are also critical theoretical reasons for studying the commons. At the heart of all social theory is the contrast between human beings motivated almost exclusively by narrow personal interests and human beings motivated by concern for others or society as a whole. The rational actor model that dominates economic theory but is also influential in sociology, political science, anthropology, and psychology postulates strict self-interest. As Adam Smith said: "We are not ready to suspect that any person is deficient in selfishness" (Smith[635], 1977[1804]:446). This assumption was what underpinned Hardin's analysis. Olson[636] (1965) brought our attention to group organizations' susceptibility to achieving common goals, like political or policy outcomes, to a paradox known as the "free-rider problem". This issue had previously been recognized by (Samuelson[637], 1954) concerning other "public goods."

In this sense, after the Baldios's land devolution in 1976, in a new socioeconomic context where modernity changed ways of life in Portugal and created new opportunities for productive work in the rural world outside the communities, making communal lands less essential for subsistence, it is interesting to see how they evolved after their return. In this sense, a brief review of the current situation is made to understand whether devolution has revitalized communities through collective actions and investment in material and social capital, creating a more participatory and supportive society and guaranteeing the safeguarding of timber resources and their environmental assets. Among the most representative activities recorded in a large universe of 810 baldios were forestry, grazing, cutting, and collecting firewood, representing around 87.7%, 83.5%, 71.8%, and 67.1 %, respectively, although with less intensity than in previous times (Baptista, 2010). In general, it can be said that the dependence of the commoners' economies on baldios was reduced. Communal lands tended to become open access spaces to non-residents and began, progressively, to be seen by the commoners as a source of a rentier income generation.

Because the success of interventions in land tenure and use systems depends on thorough work on the institutional construct and the respective forms of structural support, we will begin by transcribing the summary of the panel on Common Property Management that provided an

---

[634] Heller, M.A, (1998) – The tragedy of the anticommons: Property in the transition from Marx to markets. Harvard Law Review, 111

[635] Smith, A. (1977) [1804] A Theory of Moral Sentiments. New York: Oxford University Press.

[636] Olson, M. (1965) – The Logic of Collective Action: Public Goods and the Theory of Groups. Cambridge, MA: Harvard University Press.

[637] Samuelson, P.A. (1954) - The pure theory of public expenditure. *Review of Economics and Statistics 36:387-389.*

overview of the lessons, learned after decades of research, into how the drama of the commons unfolded. (Bromley[638], 1986; Peters[639], 1986). These, among other less relevant ones, included:

a) The need to define the performance of an institutional arrangement in terms of both environmental and human dimensions.
b) The importance of the initial situation as it affects emergence, performance, survival, and relative costs and benefits of institutional arrangements. Identifying correlations may be the best that social scientists could accomplish given the data available at the time.
c) The importance of the distinction between the characteristics of the resource (common-pool resource) and the regime that manages the resource (common property regime or some other kind of property regime). Analytical progress would be slow unless this distinction was taken seriously.
d) Since the situation of each *baldio* is particular, there is a need to compare and synthesize analyses of common-pool resources and common property regimes in various disciplines using a framework that enables scholars from different disciplinary backgrounds to communicate and compare findings.
e) The need to understand how various changes in property rights affect the distribution of income, wealth, and other resources that are important aspects of the creation and survival of institutional arrangements.
f) The need to understand how spatial and temporal heterogeneity in the resource endowment creates opportunities for some to benefit at the expense of others, thereby often exacerbating equity problems.
g) The need to compare the costs and benefits of various institutional arrangements for a given resource. Under some circumstances, common property regimes perform better than private property. This occurs when (a) the costs of creating and enforcing private property rights are high, (b) the economic value of the output produced from the resource is low, and (c) the benefits generated by the resources are distributed with high spatial uncertainty. Under these circumstances, a common property regime may provide a way of reducing the risk of having no benefits at all in a given period and thus may be preferable to private property (Runge[640], 1986).

Despite available examples, these orderly institutional arrangements on the recreation and monitoring of baldios were unavailable when the common lands were devolved to rural communities considered heirs of their historical owners in 1976. The law (Decree-Law 39/1976 of January 19) explained the concept, defined the commoners, and described the use and administrative rights. According to the statute, communities could claim their common land if they constituted themselves with "assemblies of co-owners" and elected "directive councils" to govern the common land. An administrative, self-governing, or co-administration with the public administration model was proposed.

Lawmakers forgot that land abandonment, especially in regions with small properties in mountainous areas, was already a reality in the 1970s. The exodus to cities drove young people away from these regions, with a progressive ageing of those who remained there and a structural

[638] Bromeley, D.W. (1986) – Closing comments at the conference on common property resource management, 591-597. In: *Proceedings of the Conference on Common Property Resource Management. Washington DC: Nacional Academy Press, pp.*

[639] Peters, P.E. (1986) – Conclusion statement, 615-621. In: *Proceedings of the Conference on Common Property Resource* Management. Washington DC: Nacional Academy Press, pp

[640] Runge, C. F. (1986) - Common property and collective action in economic development: 31-62. In: *National Research Council, Proceedings of the Conference on Common Property Resource Management.*

Washington, DC: National Academy Press.

change in social organization and community. After so many years, this reality of human rarefaction, of agricultural abandonment associated with the transformation of farming systems and the way of life of rural communities explains a lot about the difficulties experienced after the return of land and the voluntarism of the measures legislated without support in social and economic realities. Thus, from 1976 onwards, the return of old common grounds to the populations had little significance in recovering the traditional relationship between the people and community lands, as we attempt to show later.

In 1993, 16 years after the devolution, 78% of the 688 communities that expressed interest in managing their communal grounds expressed official interest in adopting a co-management model. However, many communities remained unable to unite and express their interest in managing the commons returned to them. Thus, a new law (Law 68/93) recognised the possibility of baldios communities being represented by the Parish Council, and only in 2005 were 186 Parish Councils registered as baldios managers.

The fact that Law 68/93 gave communities that had difficulty in creating their first Co-owners' Assembly the possibility of delegating the right to administer their common land to the respective Parish Council or City Council seems to us to be a good indicator of the lack of social cohesion or sense of community presupposed in the concept of communal property and therefore in the artificiality organised for the concession of some Baldios.

The impact on the forestry sector of the frequent legislative changes, almost always of a reactive nature, which we have witnessed over the last 47 years in a sensitive and long-maturity ecosystem, is visible, mainly in the pine forest cover: it is the strong retraction of the pine area and in the supply of pine wood to industry and a high frequency of disputes between common lands and with private properties over the definition of the limits of communal lands (Gomes[641]2018). The reduction in the covered area, the high incidence of fires and the ICNF's withdrawal from the partnership with Baldios show that the forestry sector continues to suffer from the lack of a coherent project for Portuguese forests. The lack of planning and the lack of a time perspective for a reform that would resolve the fundamental problems of the country's forestry sector are evident.

This wind in and out legislative process ends up in the current situation showing a high dominance of private forests distributed among many owners and many small plots (about 11.7 million rural properties registered in the land predial matrix on agroforestry use, of which only 46% of the forest spaces have predial registration).

The lack of a practical registry of rural properties at a national level, of a platform for registering the limits of Baldios, as enshrined in the last Wasteland Law (Law No. 75/2017), and of adequate alternative means for the extrajudicial resolution of disputes over Its limits have long been a challenge to the prompt resolution of frequent conflicts over property boundaries.

This represents a critical situation regarding the current susceptibility of our forest and represents an explicit constraint on its planning and optimization of expected common public goods due to the lack of scale and structures that allow its efficient and sustainable exploitation, guaranteeing functional procedures related to the fair distribution of benefits to everyone involved.

---

641 Gomes, P. (2018) - Origem dos conflitos, in: Miranda, A., Carvalho, A., Gomes, P., Copena, D., Lopes, L. (eds.), *Associativismo em Áreas Comun*itárias. Vila Real, p. 135 pp.

In turn, the State, with the small area of publicly owned forest and with a reduced support service and weak operational structure, and whose functions and organization have suffered frequent arrangements and amputations of responsibilities distributed by various governmental and regional entities, cannot assume acts as a corrective agent involved in practical forest management or planning in existing markets in response to unpredictable deviations from an open economy in which it operates.

The forestry management of communal lands subject to the Forestry Regime became a challenge for their co-owners since it required technical knowledge they did not possess. To mitigate this lack of technical expertise, the law allowed co-management administration systems to safeguard forest resources transferred to co-ownership administration. Surprisingly, this alternative, which allowed wastelands to mitigate the lack of expertise in forest management, was abolished with the new law in 2017.

Table AI.2 sets forth the main common lands administration models.

On a national scale, the figures reveal that in 2017, administration modalities associated with the State were predominant (72.0%).

Table AI.2 – Distribution of Baldios by administration modalities

Administration models	Baldios registered (2017)	%
Baldios managed by the Board of Directors and/or Board of the Shareholders' Assembly in association with the State	586	50
Baldios managed exclusively by the Board of Directors and/or Board of the Shareholders' Assembly	241	21
Baldios administered by Parish Councils (with or without the Shareholders' Assembly Board) in association with the State	250	21.6
Baldios managed by Parish Councils (with or without Board of Shared Assembly)	79	7
Baldios managed by Forestry Services	4	0.4
TOTAL	1160	100

Source: Kolos, (2020)

Baldio's current land utilization, outlined in Table AI.3, shows that forest land utilization (Baldio areas vary between 2,8 ha to 5349 ha, with 414 ha the mean area in the North and 508 ha the mean area in the Centre) was still very significant. According to some studies, forest exploitation is the primary source of income. In Northern Baldios, it reaches more than 80% of the total revenue value. In 2010 (AFN, 2010), as mentioned above, the Total Economic Value (TEV) of Baldios reached an estimated value of 69.5 M€ per year, corresponding to about 15% of Portuguese Forest TEV at that time (Kolos, 2020).

Table AI.3 - Forest main types of land use and forest areas classes under its domain

	Nº of answered questionnaires.		Total sum (1,000 ha)		
Baldios with forest uses	576		141.1		
Baldios with agriculture uses	764		6.5		
Baldios with shrubs & uncultivated land	613		136.3		
Other land uses	707		3.0		
Classes of forest areas	>200	50-100	10-50	0-10	Unknown
Number of baldios	165	106	111	80	114

Fonte: Kolos (2020)

Long after the Baldios have been returned to the communities, it must be said that the problem of allowing adequate management of the Portuguese Forest, or of the rural territory in general, making it more productive and more resilient to climate changes remains unfinished. This, despite Decree - Law nº 39/76 enshrining the concept of Plans for the Use of Baldios Resources (PUB) committed to the Public Administration whose reduced structure and institutional instability did not allow its implementation on time.

Once again, the gap between the law and the practical conditions for its implementation was felt. Law nº 68/93 (17 years after land devolution), the PUBs were once again redefined, by Decree-Law nº 205/99 that reinforced the obligation to submit National and Community Forests to Forest Management Plans.

In the following years, despite the consensus that one of the critical gaps in the management of Portuguese forest resources was the insufficiency of their implementation and control, the slowness of the Forestry Services' action was criticised by the associative movement of the Baldios communities, for not complying with the law as co-manager of the Baldios forest areas. Notwithstanding the recognised urgency of improving governance models in abandoned or under-managed forest areas, as reflected in the National Forest Defence Plan against Fires, as well as in the National Strategy for Forests (APIF 2005; PCM 2006) and in the protocols that have been signed with the General Directorate of the Forestry Service (the name of the Forestry Service at the time), BALADI (National Baldios Federation - National Baldio Federation) and two associative structures (FORESTIS and FPFP), a significant management gap remained. According to the study by Kolos (2020), this delay in preparing the PUBs was due to: i) the bankruptcy of one of the partners (the Federation of Forestry Producers of Portugal, FPFP) and the consequent distribution of responsibilities between BALADI and FORESTRIS; ii) disruptions in collaboration between key protocol actors; iii) the various updates to the Access structure created for PUB submissions; iv) the frequent structural reforms in the Forest Services that pulverised the sense of the importance of the national forest policy framework.

Because of this and the hasty institutional arrangements and discoordination, we witness the different approaches applied in evaluating the PUBs by the Regional Directorates of the North and the Centre of Portugal. While the PUBs prepared and presented in the North covered the total area of each Baldio unit, the Centre Forestry Directorate criticized this approach. They called for developing these plans only for the forest perimeters - the part of the Partial Forest Regime located in the Baldios lands. Once again, the insufficiency of the legislative process and the resulting interpretative gaps that harm the methods of implementing the law are evident.

According to the Kolos (2020) study, this conflict seems to justify why, of the 224 plans presented in the Centre region, only 66.5% were approved, making it impossible to track what happened to the remaining 33.5%.

Interestingly, it is worth highlighting that after 40 years of the devolution of land to the communities, data collected in 2016 with the delivery of PUBs in the Central region, new vacant Units appear without areas included in the ICNF registry referring to the 2013 Forestry Regime (Table AI.4).

Germano,[642] in 1999, reports a similar case when, in 1976, 34 new Wastelands were registered that had not been subjected to the forestry regime, obscuring the transparency of the Wasteland constitution processes and the equity in access to public instruments (Rural Development Programs and PDR2020).

Considering this support for the elaboration of Forest Management Plans (PGF) and not PUBs, there is information that, in some cases, PUBs already approved were retitled as PGF. As the scope of the PUB was not identical to that of the PGF, this can only be seen as a poor legislative organization that opens the door to interpretative facilitations that facilitate opportunism in accessing the EU's financial mechanisms.

Table AI.4 – Number of PUBs prepared by different entities (2016).

Region	BALADI	FORESTRIS	FPPFP	AFN	Total
North	288	294	11	15	608
Centre	105	63	56	--	224
Lisbon & Tagus valley	--	--	--	4	4
Total	393	357	67	19	836

Data source: Kolos, 2020

Considering this support for the elaboration of Forest Management Plans (PGF) and not PUBs, there is information that, in some cases, PUBs already approved were retitled as PGF. As the scope of the PUB was not identical to that of the PGF, this can only be seen as a poor legislative organization that opens the door to interpretative facilitations that facilitate opportunism in accessing the EU's financial mechanisms.

Given that the forest area in the Baldios domain is significant and has constituted one of its primary sources of income, and the slowness in having it managed with duly certified management plans 47 years after its return, it would be helpful to see the proportion of fire occurrences in forest areas subject to its jurisdiction. Considering *Pinus pinaster*, the main forest species in baldios forest lands, the quantitative global analysis carried out by Kolos (2020) considering property types and management modalities for the period between 1971 and 2017 revealed that the highest average annual percentage of pine forests burned for the various kinds of baldios management it was between the range 3.4% and 5.0% while public and private areas

[642] Germano, A. (1999) - *Diagnóstico dos baldios a nível nacional*. Direcção-Geral das Florestas. Lisboa.

showed significantly lower values between 2.0% and 2.1%, respectively. Regardless of their different governance models, communal lands' average annual percentage burned area was always higher than those recorded in private areas. The study mentioned above also showed that among the existing management methods in baldios, the modality with the lowest amount of burned area was the management modality by commoners with the Forest Service.

A review of the form and frequency of the involvement of Baldio members and the level of participation and social cohesion was carried out by Kolos (2020) in a sample of 661 Baldios, showing significant differences in the involvement of the number of commoners in the assemblies. The most important number of commoners' participation was observed in the Baldios managed by the Parish Councils. Interestingly, the information given to us about the differences in interpretation between the different entities regarding the concept of co-owner/commoner and Commoners Assembly makes it challenging to interpret the data.

As for the increase in the number of commoners in recent decades, observed in the context of a decrease in the rural population on a national scale, the referred author mentions that this can be explained by the requirements of access to subsidies related to pastoral activities. So, in Baldios with grasslands, outside residents can receive a document on the right to use these plots, provided they assume and fulfil their duties as commoners. It would have been helpful to know whether the shepherds who had signed a document attesting that he was a commoner continued to pay rent for the use of the pasture. We do not know whether this is an isolated fact or a current practice to enable participation in programs provided by EU funds or a widespread practice. Whether this is an isolated case or not, this distorts the concept of co-ownership of common property and a dubious use of available financial instruments.

One measure of the level of participation of co-owners is the number of Commoners Assemblies and members frequency. On average, Kolos (2020) found more than one assembly summons per year of co-owners in each baldio land in the analysis universe (776 units). Exceptions are made for common areas with administration models (board of directors in co-management) where this frequency is higher. As for the average participation in these meetings, the study showed that, in general, the average participation is low (between 9 and 34 attendances). This seems to be a sign of ageing populations and the population's growing alienation from what is happening with their so-called communal lands. The reality shows that modernity has changed ways of life across the country. The significant rural exodus has created new job opportunities outside rural communities, making communal lands less essential for the survival of the communities, many of which are reduced to older people and with less capacity to internalize technologies appropriate for the management of the lands returned to them.

The latest Baldios Law (Law 75/2017) determines that the revenues obtained from the exploitation of the Baldios are not distributable but must be invested in their economic preservation and benefit of the respective communities. Although the revenue distribution rules were part of previous laws, only in law 75/2017, 41 years after the devolution of the land, does it appear mandatory to set up a minimum reserve of 20% of the revenue for its future capitalization. However, Kolos (2020) mentions that only half of the Baldios carried them out in the last five years.

Regarding the accounts submitted to the Commoners Assembly, Kolo's (2020) analysis reveals that they do not strictly comply with the law. As the management of communal assets is subject to the accounting standardisation regime, it is difficult to justify that the in-depth study by Kolos (2020) mentions that there are differences in the way annual accounts are presented and that these are carried out differently in communal assets managed by Councils of Administration or by

Parish Councils and that, on average, in a very significant sample of Baldios analysed, only 67% of them do these calculations and only 70% present them. Skuslka et al., 2017, state that, in most cases, in the community areas managed by the Parish Councils, the income generated is seen as a source of additional revenue for the Council and subsequently diluted in its general budget, which goes against budgetary rules both for the commons and the parish administration. According to several sentences handed down by the courts, this is an illegal practice that has to be corrected when practised. The fragmentation of oversight bodies facilitates this lack of scrutiny and accountability.

These data on the constitution of a financial reserve to guarantee the sustainability of natural resources reveal that not all Baldios administrations practice them, as corroborated by other authors who point out differences between those managed under co-management and those managed independently. Thus, regarding the former, the study by Skukska, 2017, states that the investments made are shared with the State to pay expenses with Baldios land managers, payment of fuel or hours of machine work, repairs and opening of paths. In this short list, as you can see, these are current expenses and not the creation of a financial reserve for reinvestment. As for the self-managed Baldios, the investments mentioned refer to the acquisition of equipment to replace that removed by the State due to its withdrawal of co-management responsibility, as well as for social purposes (construction of churches, maintenance of cemeteries, etc.

This lack of investment in the forest heritage, revealing from our point of view the poor quality of the management process and the lack of intervention by the responsible authorities to ensure prudent management of forestry heritage and the public utility externalities generated by it, has already been noticed by Baptista et al., (2002) who observe that less than half of the Baldios have made any investment in their forest areas. The same author says that the presence of the Forestry Services did not favour a more significant commitment of the populations to the forest, which is a somewhat incomprehensible reference given the lack of forest management expertise of the baldios administration. Is this reaction not a manifestation of the lack of interest among the Baldios administration in having their forests managed by sustainable management principles?

As recent studies have shown in the current economy of exploitation of communal lands, the predominant income of the common's economy is distributed as follows: almost 50% of the commons are based on a rentier economy; no more than 10% is based on individual savings; about a third combines rentier economy and personal economy, and 7% concerns an open access economy (Baptista, 2010).

Although the yield obtained from forestry is significantly higher in terms of revenue than that from other land-based activities, frequent fires and management complexities are leading to a growing lack of interest on the part of citizens in managing these community resources and an increase in the intention to adopt other forms of land use.

Given that currently, the dominant economy in the baldios is rentier, and forestry is a complex activity that involves management plans and long-term investments that require a specific type of knowledge, it is clear that forest management is not a significant desired activity by baldios management teams more concerned with the short-term results. The indicator of investments made, and mining-type management seems enlightening to us. It is also clear that under these conditions, any intervention of the Forestry Services contradicts those objectives. Another indicator is that the most sought-after professional in the Board of Directors model is not the technical workforce but legal support, where the services provided by state institutions are scarce or even absent (Skulska et al., 2017). Perhaps it is not by chance that the new Baldios Law of 2017 provides for the complete transfer of land tenure rights to the local level, the elimination of co-administration models, and the current revenue-sharing system between Baldios and the Forest

Services over the next few years. The analysis of Baldios's governance models reveals significant differences and weaknesses, which may significantly downgrade community forest governance, especially when a growing lack of interest in the forest is detected. With the reduction of Forest Service intervention, it is not difficult to foresee a new scenario of a sharp decline in the national forest area, mainly pine forests, and worsening of the environment and increasing costs for the environment and the forest industry clusters, whose economic importance should not be forgotten.

We would say that the community grounds tend to become progressively rentable spaces for non-residents, and consequently, the primary sources of income for the community will come from the receipt of rents and compensations from those outsiders who use these goods without responsibilities in its sustainability. Regarding citizens' equity, the last baldios law in 2017 exempts its co-owners from property tax and their managers from maintaining records of income from the sale of baldio products and resources without any control or audit. This is a severe example of a lack of transparency and how the baldios could be instrumental in political arrangements that subvert the expected baldio concept. This last legal framework, which excludes the Forest Services from co-management when more than 70% of the common areas are included in the Natura protected area's network, is a future source of disputes between protection policies and the interests of baldio management. Integrating conservation into forest planning and management will be much more challenging, which is crucial to achieving the desired biodiversity goals and land multi-use landscapes like those outlined in the EU Forest and Biodiversity strategies (European Commission[643] 2013, 2015). The setting up cooperative forest management schemes and structures that require broad and transparent participation seems further away from the political objectives for implementing sustainable forest management measures and preventing their degradation.

Furthermore, it is to be feared that community control over the access of extraneous entrepreneurs to communal lands will diminish or even cease to exist or that the exploitation of the Baldios may be carried out only by tenants, without co-owners intervention and with less mediation capacity of authorities to intervene. For example, the logging that the Baldios forests are subjected to, which some have already called immoderate, is increasingly becoming a threat to the environmental balance or to the mitigating measures recommended to contain climate change and maintain water resources.

As experience in various geographies has shown, land devolution needs well-designed institutional arrangements that respond to local conditions. This implies a willingness to meet local needs and accept that the ecosystem and the social system must be reflected in policies, instruments made available and management models. This, in turn, could mean a more intense and sensible cohesive participatory approach to resource management that does not seem to be in sync under the current scenario dominated by a rentier economy and dwindling participation of co-owners to make faith in the minimal participation in the assemblies.

In sociological terms, the main assumptions that justified the devolution of communal lands, which overall consisted in a virtuous reconstruction of a solidary economy, combining traditional principles of a peasant mutual aid with principles of the market for goods and services, were

[643] European Commission (2013) - Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. A new EU Forest Strategy: For forests and the forest-based sector. Brussels: European Commission, 20.9.2013.

European Commission (2015) - Natura 2000 and Forests. Part I–II. Technical Report—2015-088. EU Commission Environment.

undermined by: i) less dependence of rural communities on their common lands; ii) growing openness of the communities to outsiders; iii) strong commoditization of their economies; iv) continued emigration of their younger populations abroad and to the coastal; v) the increasing specialization of agricultural production systems; and vi) more significant intervention of public policies in education, health and social security.

Given the quick evolution of the socio-economic context of the last four decades in Portugal and the profound changes verified in the rural environment, the increase in the environmental concerns, the conservation of resources and human desertification, the issue today is more one of knowing whether the communal lands fulfil the purposes for which they were reconstituted as recognized in the Constitution of the Republic of 1976 and with Baldios revision laws of 1982 and 2017 "land belonging to and used by territorial communities without legal personality ("people", "villages"), which are what remains of the former community forms of land ownership and means of essential productive facilities such as mills, baking ovens, threshing floors, water channels, beehives, herds, breeding animals, etc". The challenge is not only technical, but it is fundamentally a seemingly dissonance between reality and the political, legislative and institutional framework, what Festinger[644] (1957) called "cognitive dissonance, which justifies the so-called hiatus volition phase between science, politics and the public debate around a scientific consensus on the current needs and challenges of our forestry sector to face climate challenges and its vital instrument to help us achieve carbon neutrality within the assumed timetables.

Since Portugal's integration into the European Union (1986), the agricultural sector has been subject to the CAP regulations, which has since been the main guiding driver in agricultural sector policies in Portugal, and that was accentuated with the reform of the PAC (2000) and its reinforcement after 2013, and with the Europe 2020 strategy that guides the Rural Development Program (PDR) (2014-2020) to "recover agricultural and forestry ecosystems (biodiversity, water, soil ...); promote social inclusion, poverty reduction and economic development" (European Parliament, 2016) and with the political changes and socio-economic conditions that followed, the commons have been losing their meaning as a means of survival for the individual economies of each resident of the communal lands. The big question that must be asked today is whether the legal structure of Baldios is still adequate for recent times or what is needed, in terms of institutional arrangements, to give them once again the sense of utility that is imperative for the population, the environment and the country.

As in past centuries, the Portuguese forest faced upheavals and again entered a cycle of decline that must be stopped. New forms of governance are needed, as well as an increase in structured and multidisciplinary research and legislative changes that support the institutional support necessary to vitalize better and equitable participatory governance. The continued retraction of State support over the last four decades, not only in terms of its specialized technical staff but also the institutional framework and the investment and programming of forestry research itself, allows us to say that the continuation of an attitude of business-as-usual leaves a strong shadow over the development, future coverage and importance of the national forestry sector.

Although there is a broad consensus that patterns of land/environment use and the sustainability of human relations associated with their use are mainly determined by institutional interaction capable of establishing virtuous bridges between interested parties, in the Portuguese case, concerning forests, there appears to be a real gap in the institutional relationship and national agreements established under the provisions of international agreements within the scope of the SDGs. We believe it is significant in this statement to note that in the latest Baldios

[644] Festinger, L. (1957) – A Theory of Cognitive Dissonance. Stanford University Press, Stanford, CA, 291 pp

law (Law nº 75/2017), there is no reference to climate objectives, natural resources or mandatory food security requirements. The only guarantee of any connection with the environmental commitment given by the Baldio forest management associated with the ICNF in the previous law was even suppressed in the last law in force.

Annex II
Synopsis of the economic importance of the agriculture sector

The general analysis of the trade balance in the primary sector (Fig. AII.1) shows the importance of the forestry sector, evaluated by the main products, wood, cork and paper, in offsetting the deficit in the agricultural sector. Intersectoral relations are, therefore, relevant and must be considered when designing sectoral policies.

In terms of economic contribution the agriculture sector represents 1.2% of the GDP and the main produce are: fresh fruits (16.8%) and vegetables (15.7%); wine (9.3%); milk (9.6%); beef (8.3%); pork (7.9%) and poultry (7.0%) (site GPP). The agroindustry complex accounts for 3.1% of the economy.

Agri-food exports are mainly based on wine, fish products, vegetables and fruit, olive oil, milk, and dairy products. Despite the recent dynamism of its exports (annual average of 8.3% in the period 2000-2011), the agri-food complex shows levels of self-provision that reveal a strong external dependence (Fig 38). In fact, in 2022, the external deficit of the agri-food complex was -5 458.7 million euros. Trends on this unbalance show that Portugal needs to increase agricultural production and add more value in its production to increase exports and substitute imports.

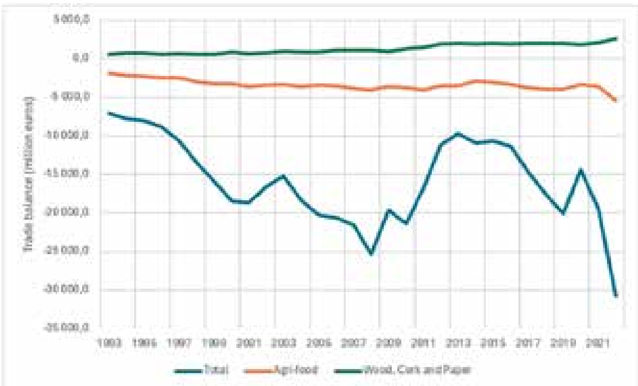


Fig. AII.1 – Trade balance in the agriculture-food sector, wood, cork and paper and total
Source: Pordata and INE 2023 (2022 values are still provisional)

The scale of supply is increasingly important in the global market. The weak concentration of agricultural supply may partly explain the fragility of the Portuguese sector. Even with specific support for producer organizations and formally constituted organizations, as in the fruit and vegetable sector, the weight of production from these producer organizations represents only 20% of the total national output compared to the 43% EU average.

A closer analysis of the agricultural sector economics shows a significant contrast between the sector's evolution within the food supply chain, as production cannot pass on the significant increases in production costs to the selling prices. The consequence is a decrease in the implicit prices of agricultural products and, consequently, weight loss in the food value chain.

The variation in other sectoral indicators, such as the contrast observed between the evolution of agricultural products in terms of value and volume, was due to the significant decrease that has been observed in the implicit prices of farm products (annual average of -3% in the period 2000 -2011) with a relative stabilisation of agricultural production prices, which grew, in the same period, at an annual average of 0.5%. This shows that the purchasing power of farmers has fallen sharply.

The productivity of agricultural work appears to have grown at a substantially higher rate than that observed in the economy as a whole. This is related either to the sharp decrease in the number and relative weight of smaller farms or to improvements and technological changes in cultural occupation. This evolution reveals farmers' capacity for innovation and adaptation, emphasising the use and modernisation of irrigation infrastructure.

Despite the strong growth in real labour productivity in 2000-2011 (30 % or 2.5 % on an annual average), the purchasing power of unitary income from agricultural labour experienced a variation from -13.5 % to -1.3 % yearly average. This decrease was not higher due to the considerable increase in the value of subsidies, which grew, on an annual average in the period 2000-11, by 3% (2.9 % net of taxes) in nominal terms, which corresponds to 0.7 % in terms of real purchasing power.

Subsidies to the sector currently represent 30 % of agricultural income. They show a regionally balanced distribution, reflecting the importance of each region in Portuguese agriculture in territorial occupation and relevance in farm production and the existence of complementarity of the support granted.

Due to the climate characteristics, with dry summers, irrigation allows high agriculture productivity growth (INE, 2014). Still, even without counting the high costs arising from investments in infrastructure, this technology has higher production costs, both with storage, transport, distribution, and operating costs and those related to energy for pumping water. The agricultural sector is Portugal's largest consumer of water, with 73% of the total volume (APA[645], 2016). In 2013, over half of the farms had irrigated crops, covering 13.2% of the UAA (INE, 2014). In recent years, there was a significant irrigation development in Alentejo, the southern region of Portugal, promoted by the Alqueva infrastructure. This area increased by 10.2% between 2009 and 2013, representing 44.6% of the national irrigated area. Punctuating mainly the agricultural landscape of Alentejo and Algarve, one can still see the substantial extension of intensive crops with a predominance of olive orchards, strawberries, blueberries, raspberries, and blackberries under greenhouse irrigation.

These changes in the agricultural landscape of southern Portugal, in a phase of unavoidable reduction in precipitation and increase in temperature, already affecting some areas of the *Natura 2000* network, require increased attention from those authorities responsible for spatial planning and environmental protection as these are unsustainable options given the current constraints imposed by climate change. In fact, water availability is a critical factor in climate change in the Mediterranean and Portugal, especially in the southern region, Alentejo and Algarve, where water deficits are increasing in absolute terms and affected areas. So, there are marked limits to the increase in irrigated areas and the use of potentially higher demanding crops that it is critical to monitor.

---

[645] APA (2016) – Volumes Captados por Sector e por Região. Agência Portuguesa do Ambiente. [rea.apambiente.pt/mode/706?language=pt-pt].