SCALING LAND-BASED MITIGATION SOLUTIONS IN PORTUGAL

LAND-BASED MITIGATION NARRATIVE CO-DESIGN

PATRÍCIA LOURENÇO AND JOSÉ RAFAEL MARQUES DA SILVA

STATUS: PUBLIC

1. Table of Contents

2. Introduction

This report includes a description of a generic nation-wide transition scenario for the implementation of land-based mitigation technologies and practices for the AFOLU sector (agriculture, forestry, and other land use sectors) in Portugal. The report shows the outcomes of a series of research steps that have been conducted in this country since the start of the project in June 2020 until the end of 2022.

First, we performed an initial scoping of key LMTs in the case study country. The scoping assessment resulted in a long list of broad portfolios of different LMTs that could be viable within the various case study countries.

Second, following this long list, we developed a short-list LMT portfolio containing key LMTs that would be the most relevant for a given country context. All case study country partners were asked to propose and validate their LMT portfolio through complementary (policy) literature review and with the help of stakeholder interviews (i.e., external validation by relevant country experts and stakeholders). AgroInsider held online meetings and interviews (due to the COVID-19 pandemic) and participated in international conferences and academic circles to engage and understand stakeholders views regarding the LMT portfolio. The list of stakeholders includes Portuguese and Spanish pastures associations, small and large national private actors from pastures, agriculture (e.g., wine production), agroforestry (e.g., Montado and Dehesa) and forestry (e.g., eucalyptus production for paper pulp) systems. Ex-ante no specific guidance of criteria for LMT portfolio short-listing was provided to allow for a free and open co-design process with stakeholders. The scoping process and results are presented in section **Error! Reference source not found.** of this report (step 1 & 2).

Third, after the short-listed LMT portfolios were validated, the LANDMARC case study country partners were asked to develop national scaling narratives or storylines for each LMT included in their portfolio. The assessments focus on climate risks, vulnerabilities as well as socio-economic co-benefits and trade-offs associated with upscaling LMTs in the case study countries. The analysis is based on a broad range of information/literature sources, and stakeholder consultations conducted. This process is supported through a risk and impact assessment (i.e., an online survey and workshops/seminar/webinars) conducted through the LANDMARC tasks 4.1, 4.2 and 5.2. The results of this analysis are a set of LMT narratives which are presented in section **Error! Reference source not found.** of this report.

The research steps are designed to enable both an **analysis of the risks and (climate) impacts of scaling up land-based mitigation and negative emission solutions**. As such this report mainly contributes to objectives 2, 3 and 4 of the six LANDMARC key objectives (see **Error! Reference source not found.**).

Table 1: LANDMARC project objectives.

	Project key objectives
1	Determine the potential and effectiveness of LMTs in GHGs mitigation using Earth Observation (EO)
2	Improve climate resilience of LMT solutions at the local level for large-scale implementation
3	Assess the risks, co-benefits, and trade-offs of scaling up local LMTs nationally

4	Scaling up LMT solutions to the continental and global level to assess effectiveness
5	Improve current methodologies to estimate emissions and removals for LMTs
6	LMT capacity building and develop new tools and services for decision making

While the results shown in this report represent a mostly qualitative storyline describing the context and impact of scaling up LMTs in a country context, they also enable project partners to proceed with the translation of the outcomes in a manner so that they can serve as direct model input.

Furthermore, these national level assessments provide a testing ground and empirical basis for the continental, and global assessment of the realistic scaling potential of land-based mitigation and negative emission solutions implemented in Work Packages 6 and 7 of the LANDMARC project (***Objective 4***).

3. Scoping of land-based mitigation solutions in Portugal

3.1 Overview of potential of LMTs in Portugal

3.1.1 Introduction

Portugal is a country with a proven track record of climate policy, being one of the 14 countries in the European Union (EU) with the best performance in effective emissions of Greenhouse Gases (GHG) that have met the objectives defined in the targets of the Kyoto Protocol, as well as the 2020 targets for reducing emissions, energy efficiency and promoting renewable energy sources.

According to the World Bank in the period 1990-2019, total Portuguese GHG emissions in kt of CO2 equivalent are composed of CO2 totals excluding short-cycle biomass burning (such as agricultural waste burning and Savannah burning) but including other biomass burning (such as forest fires, post-burn decay, peat fires and decay of drained peatlands), all anthropogenic CH4 sources, N2O sources and F-gases (HFCs, PFCs and SF6) were estimated at about 61.4 $MtCO_2eq$ in 2019, representing an increase of 9.20% compared to 1990 levels and a decrease of 7.60% compared to 2018 (Figure 1).

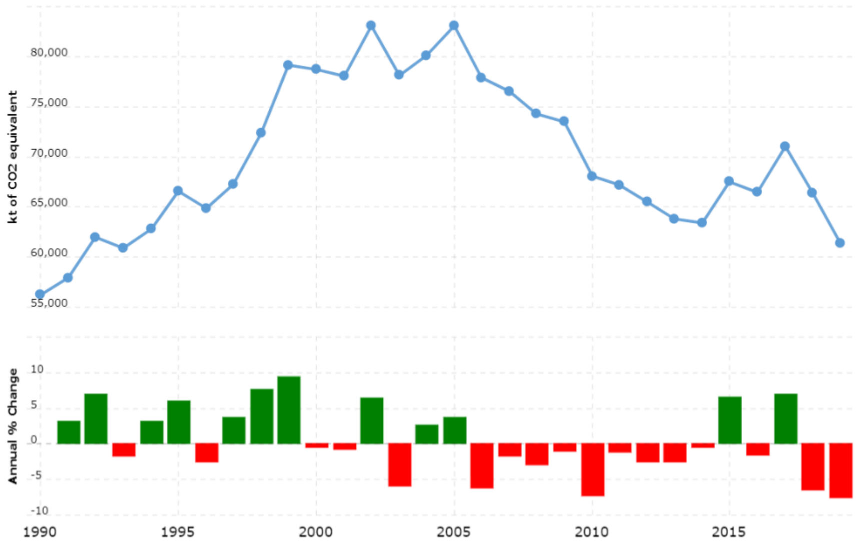

Figure 1. Evolution of greenhouse gas (GHG) emissions in Portugal between 1990 and 2019 ($ktCO_2eq$). Source: https://www.macrotrends.net/countries/PRT/portugal/ghg-greenhouse-gas-emissions'. Retrieved 2022-10-26.

During the 1990s, there was a steady increase in Portuguese emissions associated with the increase in energy demand and mobility, followed by a period of stagnation in the early 2000s and recession between 2011 and 2013, and recovery since then (Figure 1). The emission stabilisation/reduction trends started before the crisis (2005) as a result of technological improvements in pollution control systems and energy efficiency; of the introduction of less polluting fuels, with emphasis on natural gas from the late 1990s onwards; of the significant growth of energy produced from renewable sources (with special emphasis on wind); of the implementation of waste management measures, aimed at the increase of selective deposition; of reuse and recycling; and of the energy recovery of biogas generated in the waste management systems (Figure 2). In 2017, the strong growth is related to the forest fires that occurred in the tragic year of 2017, a situation associated with a particularly dry year, with high temperatures occurring outside the summer period (June and October), and with unusually strong winds, such as the Hurricane Ophelia that swept the coast of the Iberian Peninsula in October 2017. In 2018, the Forest resumed its role as a natural GHG sink with a sequestration of 6,287 kt of CO_{2eq} (Figure 3).

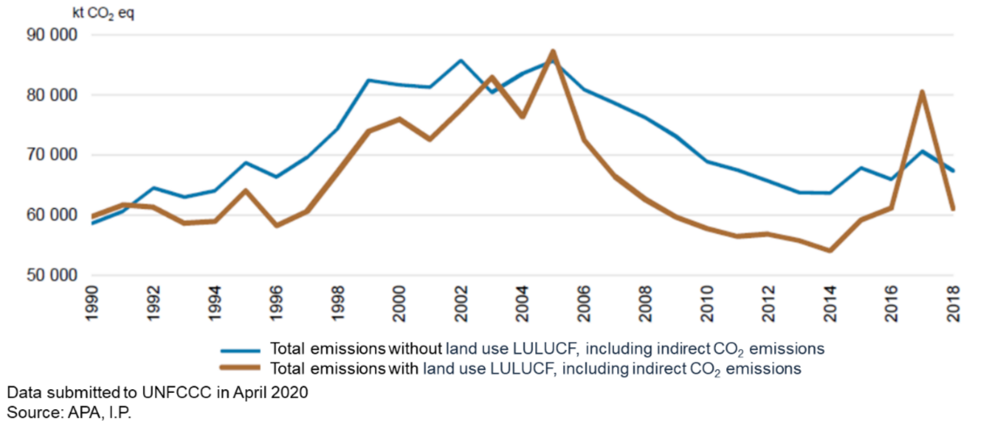

Figure 2. Greenhouse gas emissions (GHG) in Portugal between 1990 and 2018. LULUCF: Land Use, Land Use Change and Forestry. UNFCC: United Nations Framework Convention on Climate Change.

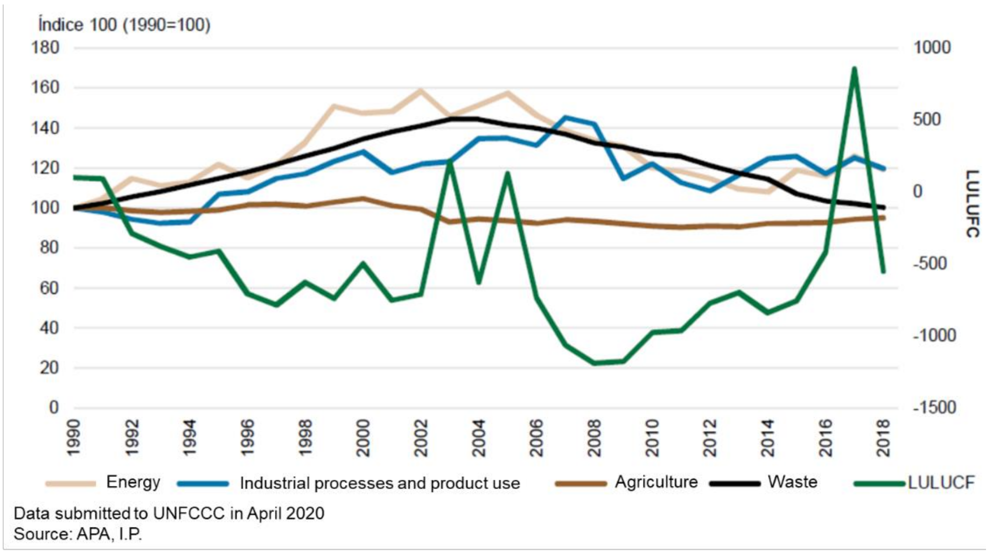

Figure 3. Greenhouse gas emissions (GHG) by emission sector in Portugal between 1990 and 2018. LULUCF: Land Use, Land Use Change and Forestry. UNFCC: United Nations Framework Convention on Climate Change.

In order to guarantee the neutrality of its emissions until the end of 2050, the Portuguese government elaborate a Carbon Neutrality Roadmap (RNC2050, 2019) to reduce emissions from -45% to -55% by 2030, - 55% to -65% in 2040 and -85% to -90% by 2050, compared to the 2005, assuming a carbon sink value of between -9 and -13 $MtCO_2$ (Figure 4). To achieve these objectives, all sectors will have to contribute, either by reducing their emissions or by increasing their carbon sink capacity.

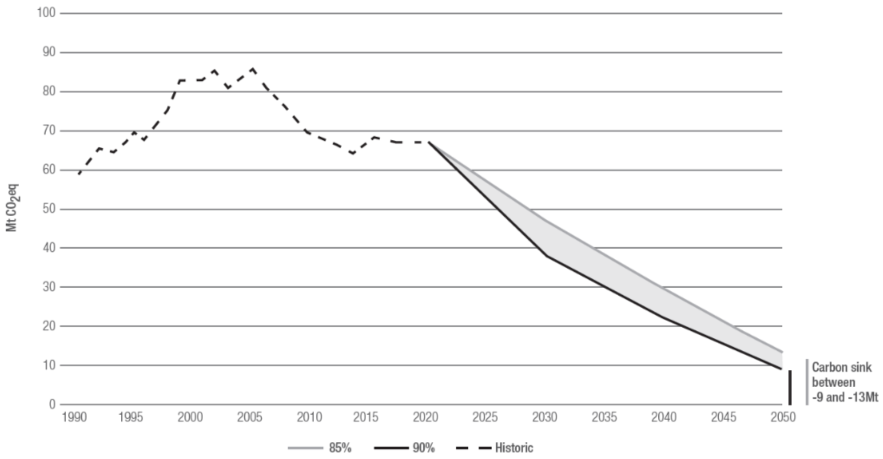

Figure 4. Emissions reduction trajectory from 85% to 90% by 2050 compared to 2005. The emissions trajectory includes net emissions from agriculture and agricultural lands, considering their carbon sink role. The value of the carbon sink does not include this component for pastures and other agricultural lands. Source: RNC2050, 2019.

3.1.2 Technologies dependent on biomass / photosynthesis

BECCS and Biochar

In Portugal, Bioenergy with Carbon Capture and Storage (BECCS) and biochar are not commonly used techniques for negative carbon emissions. Most of the Portuguese forests are for commercial forestry purposes (e.g., pulp, timber, fruit extraction). However, biomass is emerging as one of the decarbonization vectors whose consumption will grow until 2030/35, subsequently dropping to lower levels than the current ones, with the emergence or increase of other more competitive energy vectors. It is in the industrial sector that the consumption of biomass is most evident, replacing, among other sources, petroleum coke.

Instead, Portuguese policy for negative carbon emissions has focused on alternative resources, such as, solar (centralized and decentralized), wind (onshore and offshore) and hydroelectric (with and without pumping) energies. Photovoltaic solar technology will be most clearly established by increasing its importance and reaching 13 GW centralized and 13 GW decentralized by 2050. Onshore wind energy is also increasing its share significantly (almost 2.5x). These two technologies have a cost-effective potential to jointly supply 50% of the electricity generated in 2030 and 70% in 2050. Hydroelectric production using pumped water will also continue to play an important role in regulating the power system which will have a pumped hydroelectric capacity of 3.4 GW in 2030.

3.1.3 Land management practices

The evolution of emissions associated with agriculture and forests in Portugal is highly dependent on the introduction of structural changes and the types of management used for example, the evolution of the Common Agricultural Policy (CAP) (Table 2 and Figure 5). Since 1990, forests have remained stabilized, having operated as a liquid sink with annual values ranging between -6.1 MtCO_2eq and -15.4 MtCO_2eq. Land-use changes have been occurring in the Portuguese forests between different forest types, i.e., conversion of one type of forest into another (e.g., changes from *Pinus pinaster* to *Eucalyptus* sp.) or changes in dominant species in mixed forests. Other land uses, including forests, can significantly increase current sequestration levels to around 11-13 million tons of CO_2, and for this to happen, it is essential to control areas set on fire annually and to achieve productivity increases across forestry species in general (RNC2050, 2019).

Table 2. Evolution of emissions/sequestrations of the agriculture, forests and other land uses sector in Portugal. Source: RNC2050, 2019.

AGRICULTURE, FORESTS AND OTHER LAND USES	2005	2015	2020	2030	2040	2050	Δ 2050/2005
TOTAL AFOLU	8.25	-1.69	3.01	-2.84 I -4.55	-4.21 I -7.02	-5.73 I -9.44	-169% I -214%
Agriculture	6.77	6.79	6.79	6.42 I 6.3	6.33 I 5.52	6.19 I 4.74	-9% I -30%
Enteric Fermentation	3.6	3.57	3.57	3.39 I 3.32	3.41 I 2.99	3.43 I 2.69	-5% I -25%
Livestock Effluent Management	0.92	0.91	0.91	0.89 I 0.88	0.83 I 0.77	0.77 I 0.66	-17% I -29%
Rice Production	0.15	0.14	0.14	0.13	0.13	0.12 I 0.13	-19% I -12%
Agricultural Lands	2.02	2.07	2.07	1.89 I 1.85	1.84 I 1.52	1.75 I 1.12	-13% I -44%
Burning of Agricultural Waste	0.05	0.06	0.06	0.06	0.07 I 0.06	0.06	21%
Liming	0.03	0.05	0.05	0.05	0.06	0.07	136%
Land Uses	1.48	-8.48	-3.78	-9.25 I -10.85	-10.54 I -12.54	-11.92 I -14.18	-903% I -1055%
Forested Land	-2.22	-11.4	-8.67	-12.7 I -13.51	-14.03 I -15.01	-15.4 I -16.45	592% I 640%
Agricultural Land	1.36	0.63	0.8	0.63 I 0.62	0.62 I 0.59	0.61 I 0.56	-55% I -59%
Pastures	1.7	0.13	0.13	-0.75 I -0.89	-0.73 I -1.11	-0.69 I -1.32	-141% I -178%
Wetlands	0.43	0.43	0.37	0.38	0.39	0.39	-8%
Urban land	1.95	2.64	2.18	2.30	2.36 I 2.34	2.4 I 2.37	23% I 21%
Scrubland and other land uses	-1.73	-0.9	1.41	0.88 I 0.26	0.85 I 0.27	0.77 I 0.28	-144% I -116%
Agriculture, agricultural land and pasture	9.83	7.55	7.72	6.3 I 6.02	6.22 I 4.99	6.11 I 3.98	-38% I -60%
Forest and other land uses	-1.58	-9.24	-4.71	-9.14 I -10.57	-10.43 I -12.01	-11.84 I -13.42	651% I 751%

Unit: Mt CO_2e

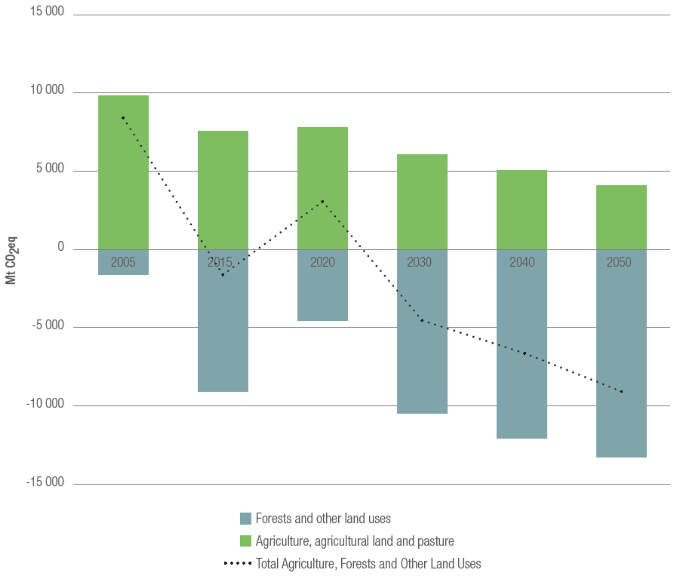

Figure 5. Evolution of emissions of the agricultural, forest and other land uses sector in Portugal between 2005 and 2050. Source: RNC2050, 2019.

In Portugal, carbon sinks are the result of some land uses, notably in agriculture, pastures, forests and scrubland, which between 2007 and 2017 absorbed from the atmosphere about -8.5 MtCO_2 (from -13 to +7 MtCO_2), or about -12% of the emissions from the other sectors. However, the size of the national carbon sink varies greatly between years, mainly due to the influence of the rural fires each year.

Afforestation

In mainland Portugal, about 35% of the total area is forest composed of four predominant forests: i) planted forests, with the objective of producing wood, in particular maritime pine (*Pinus pinaster*); ii) Montados, of native species such as cork oak (*Quercus suber*), holm oak (*Quercus ilex*) and stone pine (*Pinus pinea*), where agroforestry is inserted; iii) forests of natural regeneration, a relatively recent phase and started with the abandonment of agricultural areas; iv) intensive forestry, with exploration in a short rotation coppice system, where the eucalyptus allotone is the main species.

Over the past 60 years, reforestation with native holm oak, cork oak and stone pine species has taken place in Portugal due to the important role played by native trees, in contrast to the clear negative impacts of planted species. However, it is necessary to know the land use before reforestation since the carbon stocks associated with each land use can be very different (Table 3). For example, cork oak forestation is a much better carbon uptake mitigation option when previous land use was agriculture or pasture, and a relatively poor option in replacing other types of forest.

Table 3. Emissions associated with afforestation with cork oak, depending on previous land-use in Portugal.

Land Use before afforestation with cork oak	Emission associated with afforestation tCO2/ha	Years before new cork oak forest offsets initial emission
Pinus pinaster	110	47
Eucalyptus spp.	81	35

Quercus rotundifolia	49	21
Quercus spp.	75	32
Other broadleaves	162	69
Pinus pinea	74	32
Other conifers	60	26
Non-irrigated annual crops	2	1
Irrigated annual crops	2	1
Rice paddies	2	1
Vineyards	23	10
Olive groves	33	114
Other permanent crops	36	16
Grassland	5	2
Shrubland	50	22

In addition, afforestation in Portugal has been occurring mainly through eucalyptus plantation, an exotic, highly invasive, fast-growing subtropical tree that can be harvested and sold, whether for bioenergy, pulp, and wood pellet industry. Portugal leads Europe statistic of being the EU country with more land planted with eucalyptus (10% of Portugal's area). Eucalyptus represents an important source of national wealth which removes large amounts of carbon from the atmosphere, with a reduction prospection of 180 000 tons of CO_2 per year. Eucalyptus has the capacity to assimilate up to almost 9 tonCO_2ha/year, three times as much as that verified in the cork oak and holm oak. The renewal of the forest is done in cycles of 12 years (from planting to harvesting the tree) leading to a replacement of part of this carbon, the eucalyptus forest allows a significant increase in stocks carbon in the forest and in the soil, in the form of long-term organic matter. However, such tree plantations bring serious environmental and social impacts. Despite concerns over the impacts of eucalyptus plantations in Portugal, some communities physically uprooted eucalyptus plantations almost three decades ago, citing concerns about fires and the drying up of springs. Furthermore, the strength of the pulp and paper lobby and the large-scale migration away from rural areas have left the slopes abandoned, with landowners turning to eucalyptus as an easy way to make a small profit from land that would otherwise go unused.

Furthermore, Portuguese forests have a major problem with fires and average annual burned area due to poor management and planning, and to the extreme weather events that are occurring more frequently. To fight against this problem, greater investment is needed in the management of plots for the prevention and fighting of fires, including new afforestation and reforestation with production species (cork oak, pine and eucalyptus) or with protection and conservation species (native hardwoods). In addition, investment support policies should take ecosystem services into account, maintain forest biodiversity and, consequently, increase the carbon sink.

Soil fertility management

Agricultural land and pastures have the potential for reducing emissions rises from 40% to 60% by stop being a source of emissions and become sources of sequestration, through conservation agriculture, replacing mineral fertilizers with organic fertilizers and sowing improved and biodiverse pastures. To reduce emissions and increase sequestration, the agricultural sector must focus on a green scheme in which there are more equitable payments to farmers when they consider the environment, climate change and the country in their practices. In addition, the expansion of organic and conservation agriculture, and precision agriculture (PA) will allow a reduction in emissions associated with animal effluents and the use of fertilizers. Therefore, the emissions reduction in agriculture is occurring at a slower rate than in other sectors, inherent to the characteristics of the associated biophysical systems, which means that its weight in national emissions will be between 29% and 34% by 2050, depending on whether one considers or not the contribution of land uses.

Moreover, it is necessary to increase the capacity for carbon sequestration by increasing the organic matter content in pastures, particularly in areas with sown, improved, permanent and biodiverse pastures. The use of biodiverse pastures has a very important contribution to the net sequestration associated with the use of agricultural land in 2050. Hence, it is essential that there is an increase in biodiversity pastures of about 400% compared to 2005 (from 50 000 ha to 250 000 ha), thus resulting in a net sequestration of 0.76 Mt in 2050.

3.2 Determining the LMT scope for national level simulation modelling

In Portugal, there is a main set of LMT that comprise several LMTs including the short list of the LMT portfolio (Table 4). The LMTs included in the LMT are described below. Within the scope of the guidelines of the European Commission, the agro-environmental measure for results integrated in the Strategic Plan of the Confederation of Portuguese Farmers (CAP) for Portugal that can be applied to LMTs, include four objectives: i) Improvement of the natural regeneration of the trees and thus increase of the forest sprout; ii) Improvement of soil conditions and regeneration of its productive capacity; iii) Improvement of the composition of pastures with Mediterranean biodiverse characteristics; iv) Diversification and qualification of unique elements of the landscape, such as riparian galleries, groves of Quercineas and/or Pinus, patches of brush, Mediterranean temporary ponds and permanent ponds.

Table 4. Long-listing of relevant land-based LMTs in Portugal.

LMT	Specification	Included in national LANDMARC LMT portfolio
BECCS	Biomass play an important role in heat generation.	No
Cropland	Soil fertility management (use of organic fertilizers, use of harvest residues, cover crops, crop rotation, precision agriculture).	Yes
Grassland	Fertilized natural pastures, sown biodiverse permanent pastures rich in legumes, soil correction (e.g., in Montado/Dehesa)	Yes

Forests and other land uses	Forest management (incl. reduction of burned area and improved forest productivity).	Yes

Cropland

Sustainable practices in agriculture, such as organic and conservation agriculture, and PA reduce GHG emissions from different sources over time, such as, reduction in the use of synthetic fertilizers and substitution by organic compost. Also, these practices enhance carbon sequestration resulting from increases in soil organic matter content, namely through the promotion of biodiverse pastures. This type of agriculture will have consequences in terms of improving the efficiency of water use, allowing for productivity gains and water savings, which is a scarce and essential good to preserve. It will also be needed to study new forms of animal diet to obtain improvements in the digestibility of animal feed with a consequent positive impact on reducing emissions. Neverthless, it is also important to highlight and replicate the good examples of marketing in agri-food short circuits, which reduce energy consumption and pollutant emissions due to the lower requirements for packaging, transport and refrigeration of the products.

In addition, the opening of agricultural markets to countries outside the EU has boosted these practices with consequences to produce crops for which the country has more competitive advantages, such as vegetables, dried and fresh fruits and olives. However, on the 13th of September 2022, the European Parliament said that it wants to tighten the rules on importing products, in the context of the fight against climate change and loss of biodiversity, forcing companies to ensure that goods sold in the EU do not contribute to deforestation. The proposal put forward by the European Commission covers livestock, cocoa, coffee, palm oil, soya and wood, including products that contain, have been fed with or made from these goods, such as leather, chocolate and furniture. The assembly also wants to include pork, sheep and goat, poultry, maize and rubber, as well as charcoal and printed paper products.

Agroforestry

The Agroforestry system Montado, in Portugal, and Dehesa, in Spain, is a High Nature Value system characterized by a high complexity because of the interactions between climate, soil, pasture (natural pastures, fertilized natural pastures, and sown biodiverse permanent pastures rich in legumes), trees (e.g., pure or mix stands of cork oak, holm oak, stone pine), and animals (e.g., sheep, pigs, cows, goats). Montado/Dehesa is one of the most prominent and best preserved low-intensity farming systems in Europe. The integration of traditional land-use and biodiversity conservation that is characteristic of this system is an exemplar for the wise management of the countryside. As well as the Montado regeneration is the last frontier to the desertification process. Moreover, with a good management plan, these systems can be strong carbon sinks with low GEE emissions.

Pastures

Montado/Dehesa pastures are generally established in low fertility and high spatial variability soils. However, pasture biomass production can increase three times more and organic matter can rapidly grow in the soil with small and cheap changes such as low soil inputs correction. Moreover, improving the balance between legumes and grasses in the pasture will reduce nitrogen fertilization and promote floristic biodiversity to pollinators. Thus, fertilization and soil correction should be applied to improve soil fertility and, consequently, productivity/quality of pastures. In this context, monitoring the pasture quality is a key element in the decision-making process of a farm manager since these pastures are the main source of animal feed in extensive animal production systems in Portugal and Spain.

Forests

The forest area present in Portugal, about 1/3 of the national territory, presents problems of degradation of the forests and particularly of the soil due to the poor management of the forest stands, of incorrect agricultural practices and of the intensive exploitation of the eucalyptus. The tragic fires of 2017 exposed the problems of forest management. Since then, the government has been developing a forest defense plan that places emphasis on active forest management aimed at planning and prevention, as well as reforming the firefighting system. This plan includes improvements in forest management and production, consequent reduction of the burnt area, and reinforcement of the commitment to ecosystem services that allow and contribute to the fight against desertification and to the valorisation of the territory, being one of the foundations of territorial cohesion. To contribute to the sink potential of the forest area will have to be reinforced, assuming its management in the articulation of territorial planning aspects, investing in management practices and models that enhance the role of sinking forests and increase their resilience in the face of climate change, which has the potential for worsening conditions for forest fires and soil degradation.

Excluded options from the short list of LMTs

BECCS

In Portugal, there is no national strategy to increase the forest area for the use of biomass as an energy source. Although the consumption of industrial biomass may grow until 2035, this source will eventually be replaced by a more competitive energy source. Currently, only 5.61% of the total electricity production in mainland Portugal is generated by biomass.

However, renewable sources consumption are very important LMTs in Portugal having already surpassed the non-renewable energy by 42.3% with the remaining 6.7% of energy consumption to be imported (which may or may not be renewable) in 2019. In 2021, renewable energy production supplied 59% of electricity consumption in Portugal, with emphasis on wind energy, which represented 26%, while non-renewable production supplied 31%. According to the National Energy Networks (REN), of the 59% of electricity consumption supplied by energy production from renewable sources last year, 26% correspond to wind energy, 27% to hydroelectric power, 7% to biomass and 3.5% the photovoltaic. Of the 31% of electricity consumption supplied by non-renewable energy production in

2021, 29% is coal, with the last plant closed at the end of November (Pego, in Abrantes) representing less than 2%. The remaining 10% correspond to importation. Between January and September 2022, 31,225 GWh of electricity were generated in mainland Portugal, of which 54.5% came from renewable sources.

Portugal has been positioned as one of the countries in the world that uses more renewable energy, such as solar, wind and hydroelectric. Despite the renewable energy being very important energy source in Portugal, they were excluded from the short list of LMTs for not being part of the scope of the LANDMARC project focus which is focus on LMTs in agriculture, agroforestry and other land uses changes.

3.3 Discussion on short-listing LMTs

3.3.1 Land use change dynamics

According to the short list of LMTs and based on the estimated data for 2050 in Table 5, the Portuguese forest area will remain relatively constant. An increase in the rate of new afforestation is expected to 8,000 ha/year (expansion of the forest area to other land uses) and a decrease in the rate of expansion of other land uses, particularly in urbanized areas, flooded dams and scrubland. The afforestation trend will be focused on planting trees of low- growing species and protection against fire, as is the case of cork oak and stone pine, reducing in this way fast-growing and fire-susceptible tree species, such as eucalyptus, maritime pine and other resinous trees. The Portuguese Forest policies measures will push the low growing species because of their better resistance to climate change and for allowing exploitation in multifunctional systems, with annual or periodic/regular revenues and with characteristics that can make a very relevant contribution to economic valorization, job creation, fire risk reduction, etc., complementing or replacing woody productions. Thus, Portuguese forestry will be diversified to be more resilient and less vulnerable in the event of drought or cold or heat wave and consequently mitigate the fires prevention.

The trend of agricultural area is to decrease with the abandonment of some marginal lands which, from the point of view of agricultural competitiveness, are not very high. These marginal agricultural areas will change to areas of pasture or scrubland. The pasture area will increase due to the abandonment of agricultural land and marginal land because of the competitiveness of agriculture. Moreover, the Montado/dehesa pastures will become better preserved.

Table 5. Evolution of the area of different land uses in Portugal (RNC2050, 2019).

LAND USE	2015	2020	2030	2040	2050	Δ 2050/2005
NATIONAL TOTAL	9.24	9.24	9.24	9.24	9.24	0%
Forested Land	4.36	4.19	4.19 I 4.23	4.18 I 4.27	4.17 I 4.31	-4% I -1%
Maritime pine	1.18	1.10	1.08 I 1.05	1.07 I 1.01	1.06 I 0.97	-10% I -18%
Cork Oak	0.93	0.94	0.95 I 0.98	0.96 I 1.02	0.97 I 1.06	4% I 14%
Eucalyptus	0.85	0.78	0.8 I 0.74	0.81 I 0.71	0.83 I 0.67	-3% I -21%
Holm Oak	0.60	0.60	0.59 I 0.61	0.59 I 0.63	0.59 I 0.65	-2% I 9%
Oaks	0.21	0.21	0.2 I 0.23	0.2 I 0.25	0.2 I 0.27	-6% I 28%
Other leafy trees	0.35	0.36	0.34 I 0.38	0.33 I 0.4	0.31 I 0.42	-10% I 21%
Stone pine	0.21	0.21	0.21 I 0.21	0.21 I 0.22	0.21 I 0.23	2% I 10%
Other resinous trees	0.03	0.01	0.01 I 0.02	0 I 0.03	0 I 0.03	-90% I 21%
Agricultural land	2.39	2.39	2.25	2.17 I 2.11	2.16 I 1.99	-10% I -17%
Pastures	0.66	0.60	0.66 I 0.66	0.8 I 0.57	0.96 I 0.49	46% I -26%
Wetlands	0.20	0.20	0.21	0.21	0.21	8%
Urban land	0.50	0.52	0.55	0.56 I 0.56	0.57 I 0.56	15% I 13%
Scrubland and other land uses	1.14	1.33	1.39 I 1.34	1.31 I 1.53	1.17 I 1.68	3% I 48%

[1,000,000 ha]

3.3.2 Land management dynamics

Portugal intents to promote the annual increment of carbon sequestered forests and pastures land management dynamics to accomplish the GHG emissions targets set by 2050 (Table 6). Once Portugal is part of the Mediterranean region, fire is an integral and structuring part of ecosystems which should not ended but ensure that it has low intensity, resulting in smaller impacts.

Thus, the main management dynamic implemented in forests will be: i) making greater use of fire prevention techniques, including reforestation with suitable tree species (e.g., cork oak and cork holm); ii) tree understory deforestation; iii) increasing the organic matter in the soil; iv) promote permanent pastures; v) increasing the use of small ruminants to reduce the combustible material; and vi) using renewable energies and local fertilizers. In this way, it is estimated that there will be a large reduction in the burned areas from an average of about 164,000 ha/year between 1998 and 2017 to 70,000 ha/year by 2050 (i.e., a 60% reduction).

Table 6. Carbon sequestration in Portugal by 2050 (Alvarenga et al., 2017).

	2014	Maximum area available	Annual increment		Total carbon Sequestered
	(ha)	(ha)	(ha)	%	(t CO_2)
Biodiversity pastures	137 000	963 000	12 000	8.8	7 919 520
Native forest	180 000	725 000	21 585	12.0	11 493 519
Total	317 000	1 688 000	33 585	20.8	19 413 039

Cropland changes will consist in the replacement of mineral fertilization by organic fertilization, the reduction of the total quantities of fertilizers used and an increase in the organic matter content of agricultural land using for example cover crops. Replacing mineral fertilisers with organic fertilisers will increase the use of compost from livestock waste and/or organic waste from other sources (e.g., agribusiness). Replacement with organic fertilisers, especially composting, is expected to reach 180,000 ha by 2050. On the other hand, it is also estimated that the total amount of fertiliser used per unit area will be reduced through the expansion and development of PA techniques, totalling 300,000 ha in 2050, which will lead to a 58% reduction in the use of synthetic nitrogen compared to 2005. These changes will contribute to the objectives and targets of the Farm to Fork Strategy and The European Green Deal by reducing the use of fertilizers by at least 20% by 2030 due to nutrient losses by 50%, and by reducing chemical and hazardous pesticides by 50% by 2030. Consequently, agricultural land will be undergone an increase in organic matter content following an increase in carbon sequestration capacity by increasing the area under conservation (or regenerative) agriculture, reaching 180,000 ha by 2050 and increasing the area under biological cultivation and/or replacement of mineral fertilization by organic fertilization. All these measures will lead to total reductions of -177 ktCO_2eq in 2030, -331 ktCO_2eq in 2040 and -639 ktCO_2eq in 2050.

Agroforestry ecosystems with a high environmental value, i.e., Montado/Dehesa, are adopting collective management and exploitation models to protect biodiversity and enhance the natural capital of territories and the services provided by ecosystems. With low soil inputs correction and the correct balance between grasses and legumes, biomass production can be tripled, and soil organic matter can rapidly grow in the soil. Thus, a shift from natural pastures to biodiversity seeded pastures can lead to an estimated a carbon sequestration factor of 6.48 tCO_2/ha/year over a period of 10 years (Teixeira et al., 2011). In addition, it is estimated that the Mediterranean forests retain up to 14 million tonnes of CO_2 every year, a notable contribution to the reduction of GHG, the main source of climate change. In the case of Portugal alone, the retention of CO_2 associated with cork oak forests is around five million tons/year (5% of total CO_2 emissions in the country). A stripped cork oak fixes, on average, five times more CO_2 during the natural regeneration process than a non-stripped cork oak.

4. Co-design of LMT narratives

4.1 Introduction

The literature review allowed to select from the long list of LMTs, a short list of LMTs representative of the Portuguese systems. The three selected LMTs will later be considered to analyze the techniques used to scale up at local, regional, national and global level through models in order to meet the objectives of the LANDMARC project. To do so, it is necessary to proceed with a description or narrative of the short list of selected LMTs. To accomplish this objective the following sections, provide the quality narrative for the three LMTs for Portugal: Section 3.2) Cropland; Section 3.3) Grassland; and Section 3.4) Forests and other land uses.

4.2 Precision agriculture

4.2.1 Introduction

PA is more innovative, more sophisticated, more productive and more market oriented with the adoption and investment in new technologies, namely technologies for inputs optimization (e.g., soil, water, plants, fertilization, pesticides…) and environment impact reduction. Some PA front runners in Portugal implemented sustainable practices and exploitation of resources considering the European Policies (e.g., Green Deal and Farm to Fork) and consumer sustainable concerns, in line with modern concepts of environmental protection, mitigation of climate change and combating desertification. These practices translate effectively in the reduction of GHG emissions from different sources over time, such as, reduction in the use of synthetic fertilizers and substitution by organic compost, the use of cover crops in between crops, the use of inputs differential distribution, etc. These changes in the sector have allowed an increase in productivity and a more efficient use of resources, improving the competitiveness of farms who puted in practice PA activities, and increase carbon sinks with low GHG emissions. Moreover, technological advances have also made it possible to respond to the demands of the market and productivity, with research being a key point in its development. The progress of the Portuguese agriculture is, in turn, a factor in the development of industrial activity, namely the agri-food industry, the manufacture of agricultural equipment and plant protection products.

4.2.2 Policy context

Considering the ambitions demonstrated by the European institutions in terms of relaunching the economy, protecting the environment and increasing biodiversity, namely through the recently approved European Recovery Plan and the European Ecological Pact - "Green Deal" – the CAP is promoting activities related to agriculture in a context of sustainable exploitation of resources, in line with modern concepts of environmental protection, mitigation of climate change and combating desertification.

In Portugal, there are highly qualified farmers ("front runners") who use PA techniques (state-of-the-art technology), conservation farming, biological farming and the use of composting, which will allow a reduction in emissions from synthetic fertilizers and their replacement with organic fertilizers, a reduction in emissions from livestock systems by increasing the quality of the diet and installing biodiverse pastures. Farmers and many producer associations improved their products and processes, such as fruits and vegetables, as well as olive oil, wine or cork, thus enabling them to compete with the best producers in the world. In the agricultural sector, there is professional training that is mandatory, by national or community imposition, in which CAP develops a considerable activity, and training to develop specific technical skills. However, there are still a significant number of companies that do not have specific training. Moreover, in recent years, there has been a growing market interest in organic products that will force greater promotion of national production and exports, a better organization of production and marketing and a reduction in the external food deficit.

The overall amount of additional investments in some of the technologies identified, which can lead to reductions in fertiliser emissions and increases in carbon sequestration on agricultural land, pastures and forests, amounts to around EUR 570 million over the period 2021-2050, equivalent to an annual amount of around 19 million euros.

4.2.3 Current land use and potential land-use competition

The importance of GHG agriculture emissions to total national emissions (excluding LULUCF and international bunkers) has decreased from 12.1% in 1990 to 9.8 % in 2017. Emissions from agriculture have been increasing since 2013, mainly because of the increase in livestock numbers, particularly non-dairy cattle. In 2015, GHG emissions from agriculture represent about 10% of national emissions, totalling 6.8 $MtCO_2eq$, and mainly involve methane (CH_4), corresponding to 40% of national emissions of this gas, and nitrous oxide (N_2O) which in this case represents 73% of the total national emissions of this gas. The most important emission sources originate from the animal sector, and represent 83% of agricultural emissions (e.g., enteric fermentation, livestock effluent management, direct manure spreading on pastures and application of livestock effluents on agricultural lands). The remaining 17% refer to the use of mineral fertilisers, lime correctors and crop residues not removed from agricultural lands. The component associated with agricultural and pasture uses in 2015 represented about 0.7 $MtCO_2eq$ of emissions, resulting from the kinds of practices used and the conversions between the different use categories to these categories over the last 20 years. Considering this component, thus associating all activities and impacts on the land of this sector, agricultural emissions in 2015 represented 11% of total emissions.

The management of the agricultural sector aims to a more effective climate action and better protection of the environment and biodiversity. To reduce emissions and increase sequestration, the agricultural sector must focus on a green scheme in which there are more equitable payments to farmers when they consider the environment, climate change and the country in their practices. In the case of the livestock sector, emission reductions can occur through improvements in food digestibility and in livestock effluent management systems. The use of biodiverse pastures has a very important contribution to the net sequestration associated with the use of agricultural land in 2050 (e.g., biodiverse pastures covering the soil in between lines of oliveyards and vineyards, sequestering carbon, reducing nutrients leaching and soil erosion).

In addition, the expansion of organic and conservation agriculture, and PA will allow a reduction in emissions associated with animal effluents and the use of fertilizers. Therefore, the emissions reduction in agriculture is occurring at a slower rate than in other sectors, inherent to the characteristics of the associated biophysical systems, which means that its weight in national emissions will be between 29% and 34% by 2050, depending on whether one considers or not the contribution of land uses (please see Table 1 from 1.4.3 Land management practices).

The evolution of the Portuguese economy and society in the last 50 years, although positive, has not stopped the population exodus to large urban centers and the progressive aging of the rural population, leading to the abandonment of territories and traditional activities in agriculture. Consequently, it gave rise to the progressive extension of forest use, often spontaneous and not managed with great concentration of fuel loads and strong exposure to rural fire hazard, which had the tragic consequences of the summer of 2017 with loss of human lives and countless losses in equipment and goods, which are added to the destruction of the forest and the goods and services it produces, further promoting the abandonment of these territories.

However, at this stage and considering cropland optimization the only way to go is to consider the usage of sustainable agriculture practices, namely PA techniques and others that for sure will start to exist in the fields to solve the labor deficit in agriculture (e.g., robotics).

4.2.4 Climate risks & sensitivities

The agricultural sector faces a major challenge in terms of adapting to climate change and mitigating its effects. It should be noted that agriculture, while being part of the problem, is also part of the solution as it plays an important role in carbon sequestration. Indeed, agriculture depends on natural resources and climate to provide a suitable environment for growing crops and climate change threatens to cause great damage to agriculture in the future. There are several mitigation and adaptation opportunities in agriculture. Many agricultural practices that are beneficial for mitigation also make positive contributions to water, soil and biodiversity protection, as well as to adaptation. For example, including grasses in crop rotations decreases emissions while providing year-round ground cover, thus reducing soil erosion and increasing soil water retention. Many of these actions can reduce the sector's impact on climate change, maintaining productivity levels to meet food demand.

In a climate change scenario, the rise in the average sea level can make the agricultural use of certain soils in coastal areas unfeasible as a result of either the rise in the water table, the total flooding of the plots, or even the increase in salinity.

Although agricultural systems are extremely climate dependent, so far, there is little documented evidence of ongoing climate change impacts. This fact is probably due to the great influence of aspects not related to the climate, such as irrigation, the management of crops and technological innovations, as well as markets and subsidy policies. Globally, agricultural productivity shows a growing trend over the last 40 years, as a result of technological improvements in breeding, pest and disease control, fertilization and mechanization. Thus, it is difficult to identify effects of recent climate change on agricultural productivity.

It is however possible to find evidence of impacts on other aspects related to agricultural activity. Crop phenology is one of the processes that highlights some effects of current climate change, particularly in perennial crops such as fruit trees, vines and olive groves. In fact, in annual crops, the sowing date can be chosen, which allows an adjustment depending on the thermal regime of each year.

In Portugal, this type of LMT considers inputs and systems optimization and because of that the mitigation strategies should be different from the North of the country (growing biomass potential when there exist a rising in average temperature) when compared to the South of the country (decreasing of biomass potential when there exist a rising in average temperature). However, the last one is only true for rainfed crops but not true for irrigated crops.

4.2.5 Economic implications

In 2030, the European Union wants 25% of the agricultural area to be under organic farming, which corresponds to 39.2 million hectares, that is, an increase of 26.7 million hectares compared to 2019. With 27 Member States, the agricultural area of the European Union is 156.7 million hectares. In 2019, around 8% of this area was occupied by biological agriculture, that is, around 12.5 million hectares. In Portugal, the organic farming area represents 6% of the agricultural area. The distribution of organic farming in the EU-27 and Portugal in 2019 is as follows (Portuguese Environmental Agency, 2019):

	Arable crops	**Permanent pastures**	**Permanent crops**
EU 27	45 %	45 %	10 %
Portugal	20%	60 %	20 %

In the specific case of Portugal, agricultural production will result in a significant increase in imports, consequently in maritime and road transport, and, consequently, in the carbon footprint of food. However, the situation in Portugal is quite sensitive, since the national agro-industry has a weight of raw materials imported from third countries and intra-community transactions much higher than the average of the European Union.

In order to achieve greater environmental sustainability in the context of Portuguese agriculture, it will be necessary to create the institutional political conditions capable of promoting an expansion throughout the national territory of production systems and the occupation and use of agricultural and forestry soils based on crops, technologies and practices that, being economically viable, contribute to: i) fighting climate change; ii) a sustainable management of natural resources; iii) the preservation of biodiversity and rural landscape. To achieve these three different contributions to greater environmental sustainability, three types of interventions are needed: 1) the good agricultural and environmental conditions provided for under the new conditions that all farmers will have to comply with in order to benefit from different future public support; 2) the eco-regime payments that will integrate the 1st Pillar of the CAP post-2020, replacing the "greening" payments in force; 3) payments for environmental, climate and other management commitments, which are expected to form part of the 2nd Pillar of the CAP and which will essentially correspond to an adaptation of the system of agri-environmental measures (MAA) currently in force.

In Portugal, income support to producers subject to conditions of an environmental nature, usually called "greening" payments, correspond to a total value of 166 million euros. Support for producers' dependent on the choice of agricultural practices beneficial from the point of view of the climate and the environment, known as eco-regime payments, corresponds to an annual value of 126 million euros.

4.2.6 Co-benefits and trade-offs

Weather conditions drastically affect agricultural productivity. The geographic distribution of crops and pastures is a function of climate and photoperiod. The total amount of precipitation, as well as its pattern of variation, are important aspects for agrarian systems. Crops have climatic limits that affect their growth, development and productivity. There are also climatic factors limiting productivity that are only effective for a few days, as in the case of cereals and fruit trees. These include temperature values associated with specific phenological phases and that condition the formation of reproductive organs, such as grains and fruits. Thus, it is easy to predict that climate change will have a strong impact on agricultural activity. The main effects, however, are the impacts of global warming on phenology and the increase of CO_2 on the photosynthetic efficiency of crops.

Those two effects can have antagonistic consequences. On the one hand, warming reduces crop cycle times and therefore productivity. On the other hand, increasing CO_2 increases the photosynthetic rate and therefore productivity. What will be at stake will be to verify if the reduction in the cycle duration is compensated by the increase in the photosynthetic rate. Depending on the balance between the two components, the result can be different, from a drop in productivity to an increase. It is logical that in that balance there are many other determining variables, the main one being water availability. Without these, crops will not be able to take advantage of the increase in CO_2. Other key variables in the balance between cycle length and photosynthetic rate are the impacts of changes in pests, diseases and weeds.

In permanent crops, there will be an anticipation of the beginning of the vegetative cycle. In annual crops, it will be possible to sow earlier and, in some cases, the possibility of carrying out two sowings each year. The areas of crop aptitude will tend to expand to North, making it possible to introduce new crops with greater thermal needs (and/or lesser water requirements) and make others unfeasible. The occurrence of extreme weather events, such as, heat waves, hailstorms or dry spells can compromise part or all the production of a campaign. In a climate change scenario, the probability of occurrence of these events is greater, so it is possible to predict greater production losses.

Considering PA techniques, which is defined as "techniques that monitor and optimize production processes ... thereby conceivably increasing yields and outputs and improving the efficiency and effectiveness of inputs" (Fraser, 2019), co-benefits and trade-offs will vary from crop to crop. Irrigated crops will benefit more from these types of techniques and technologies in terms of getting more production, reduce nitrogen emissions and beneficiate water quality impacts (Sishodia et al., 2020). On the other hand, these same techniques highlight the relevance of integrating specific ecological principles and biodiversity management procedures into agroscape management, while optimizing inputs to maximize yields (Loures et al., 2020). PA techniques, when applied correctly, provide important ecosystem benefits, such as mitigating agricultural pollution and reducing water consumption (i.e. , avoid excessive chemical inputs in soil, reduce carbon footprint in field operations, reduce herbicide and pesticide use, and monitor plant health) while reducing input costs, maximizing yields, reducing dependence on external inputs and sustain or enhance ecosystem services (Loures et al., 2020; Schrijver et al., 2016).

4.2.7 Risks associated with scaling up

Despite of being a small country, Portugal has a very marked thermal gradient and geographic characteristics between North and South regions which has different implications for the techniques to be used in agriculture. The North and Centre regions are characterized by small crops areas (< 20 ha) due to the relief. However, the crops of these regions are not so affected by the lack of water but by the pattern of rainfall and temperature variation. The South regions (Alentejo) corresponds to about 1/3 of the territory of mainland Portugal. It is a region with low population density, but with a high agricultural potential. The lack of water in this region has been one of the main constraints on its development, preventing the modernization of agriculture and sustainability in public supply. Located in the Alentejo (South region), the Alqueva Multipurpose Development (EFMA) has about 120 thousand irrigated hectares, which makes this project a structuring instrument, mobilizing a diversified set of activities, supported by an integrated development process. Taking advantage of available water resources, alternatives that are economically, socially and environmentally sustainable must be sought and supported. At EFMA, there has been a tendency to change the crop occupation towards an increase in the weight of permanent crops, as a result of the growing importance of olive and almond groves. In fact, permanent crops had a stronger growth than annual crops. Thus, permanent crops started from an initial position of 64% to the current 83%. This increase is all the more relevant when permanent cropping systems have been replaced by other. On the other hand, from the analysis of the origin of the investment, it appears that the annual crops are almost exclusively Portuguese and the permanent crops, with a very significant weight, are from foreign investors.

In terms of PA techniques, scalability is possible mainly when using remote sensing tools. This scalability is possible in the south of the country (Alentejo) but not in other types of regions, such as the small property typical of the northern regions of the country.

4.2.8 Research gaps

No research gaps have been identified.

4.3 Grassland

4.3.1 Introduction

Grasslands have the availability of capturing carbon and also emit GHG. Grasslands are generally expected to have high biomass turnover, productivity and nutrient cycle, and only moderate capacity for carbon sequestration in biomass when compared to woody communities. Therefore, not all area available for sown biodiverse grassland is available for sequestering carbon and neutralize emissions.

A particular activity, taking place in grazed lands is reported and accounted for under "grassland remaining grassland": Sown Biodiverse Permanent Pastures Rich in Legumes (SBPPRL) sown biodiverse permanent grassland rich in legumes. Sown biodiverse grasslands are based on a diverse mixture of about twenty different species, many of which (approximately 30-50%) are legumes. These grasslands are more productive than the baseline land use system – spontaneous natural grasslands. Productivity is accompanied by an increase in soil organic matter (SOM) and correspondent carbon sequestration. Teixeira et al. (2011) analyzed the effect from a shift from natural to sown biodiverse grasslands, and calculations based on this work estimated a carbon sequestration factor of 6.48 $tCO_2.ha^{-1}.yr^{-1}$ for a period of 10 years. Most of the time, these grasslands are grazed directly by cattle, sheep or goats and result from the seeding with improved and selected seeds. Thus, grazing intensity and opportunity can influence pasture growth and thus affect soil carbon storage. Both undergrazing and overgrazing can decrease soil carbon build-up. In addition, pastures that favor the intercropping of different species should be used. It increases grassland productivity by increasing soil carbon sequestration.

A grassland study showed that the composition of the species community is sensitive to CO_2 increase, which has implications for its stability and resilience. For example, in an annual Mediterranean grassland after three years of trials, species diversity decreased with increasing CO_2, increased with increasing precipitation and showed no effect with increasing temperature. In sown grassland, the increase in CO_2 favored legumes.

The increase in climate variability, with more frequent occurrence of extreme events will also have a negative effect on agricultural activity as it will increase the uncertainty associated with different agricultural systems. On the other hand, the increase in extreme events can lower crop productivity more than the effect of increasing average values. This results from the fact that the impact of extreme events largely depends on the phenological state of the crop at that time. The more frequent occurrence of more intense rainfall will have a negative impact on productivity as it increases the occurrence of periods of saturated soil and, consequently, of stress for crops. Those events will also have impacts at the level of soil erosion.

4.3.2 Policy context

According to the trajectories for carbon neutrality of the Portuguese economy by 2050, it is necessary to ensure the capacity for carbon sequestration by increasing the organic matter content in grasslands, especially in areas with sown, improved, permanent and biodiverse grasslands. The use of biodiverse grassland has a very important contribution to the net sequestration associated with the use of agricultural land in 2050.

In a similar way to croplands, the expansion of biological and conservation farming and PA, as well as permanent grasslands, will reduce emissions associated with fertilizer use and animal effluents, and increase carbon sequestration resulting from increases in organic matter content in the soil. These approaches are highly being used by highly qualified farmers who use state-of-the-art technology, including sowing biodiverse grasslands which induce other environmental benefits, such as the preservation of natural and ecological resources, promotion of biodiversity and/or improvements in animal welfare.

4.3.3 Current land use and potential land-use competition

Contrary to cropland, the areas of grassland have seen an increase since 1990, with most of the area coming from cropland (rain-fed annual crops). The conversion from agriculture to grasslands usually results in an increased sequestration, while the conversions from forest land and other land result in increased emissions. The net-balance has favoured emissions, although these have been heavily reduced since 1990. More recently the introduction of incentives for biodiverse grasslands has allowed an increase in sequestration rates due to an increase in the areas of grasslands and extensive livestock, the greater use of more sustainable practices in environmental terms (e.g., organic production, integrated production, direct sowing and minimal mobilization) and the reduction in the use of fertilizers.

Furthermore, permanent grasslands will increase the capacity of carbon sequestration by sowing improved and biodiverse grasslands which consequently will increase the organic matter content in the soil. With low soil inputs correction, biomass production can be tripled, and soil organic matter can rapidly grow in the soil. For instance, improving the balance between legumes and grasses in the grassland, the technology will reduce nitrogen fertilization and promote floristic biodiversity to pollinators. Fertilization and soil correction should be applied to improve soil fertility and, consequently, productivity/quality of grasslands. Therefore, not all area available for sown biodiverse grasslands is available for sequestering carbon to neutralize emissions.

Moreover, it is necessary to ensure an increase in the organic matter content of the land area used for grassland, focusing in particular on areas with sown, improved, permanent and biodiverse grasslands in order to increase their sequestration capacity. This requires an increase in biodiversity grasslands of about 400% compared to 2005 (from 50 000 ha to 250 000 ha), thus resulting in a net sequestration of 0.76 Mt in 2050.

4.3.4 Climate risks & sensitivities

Climatic conditions drastically affect grassland productivity in the same way affect the productivity of crops. The geographic distribution of grasslands is a function of climate and photoperiod, total amount of precipitation and effect of temperature on phenological development. The occurrence of extreme weather events, such as, heat waves, hailstorms or dry spells can compromise part or all the production of a campaign. In a climate change scenario, the probability of occurrence of these events is greater, so it is possible to predict greater production losses in this way.

4.3.5 Economic implications

In Portugal, and according to INE (2020), the area of permanent grasslands grew 14% compared to the last agricultural census carried out – Agricultural Census 2009 (RA09), which means that this important agrarian system occupies about 60% of the Useful Agricultural Area (SAU) in Portugal. There is a great diversity of permanent grasslands (e.g., natural and sown, on clean land and under cover of Montado) and, therefore, several management strategies. In some of these grasslands, it is justified to define and apply strategies for their recovery or improvement, to be able to increase their productivity by reducing their production irregularity, to improve the quality and also to increase the different ecosystem benefits produced, that is, to obtain a grassland with a sustainable management method.

Currently in Portugal, sustainable biodiverse grassland is being implemented where, through the increase of leguminous species in the mixtures to be used, instead of the traditional permanent ryegrass grasslands. It is intended to reduce the use of nitrogen fertilizers and its environmental impact, increase the production of biomass and soil fertility and contribute to an increase in the volume and quality of dairy production. At the same time, it is expected to reduce production costs and consumption of concentrated feed and raw materials needed for its manufacture. The production of GHG resulting from the processes of manufacturing and transporting compound feed and fertilizers from the continent is also reduced. Thus, framing a logic of Circular Economy, with the corresponding positive impact on climate change.

4.3.6 Co-benefits and trade-offs

The contribution of grasslands and forages to Portuguese agriculture has not been properly recognized or taken advantage of. It is 2/3 of the agricultural area that is occupied by these crops that support animal production (especially ruminants) which are cheaper and of better quality. There is a lack of definition of national strategies to encourage the use of more productive, more resilient and persistent species and mixtures, and improvement in the management of installed pastures (e.g., sowing, fertilization, mineral correction, animal management, etc.) is lacking.

Direct aids (i.e., integrated production, organic production, greening, etc.) are neither sufficient nor adequate to promote the improvement of production and the impact of forage and grass crops. More research and experimentation are needed, on species, varieties, mixtures, cultural techniques and the management of grasslands and animals to increase the efficiency of the use of these foods, their quality, reduce costs, improve animal performance and, above all, increase the effective animal/animal load to better value natural meadows and grasslands.

4.3.7 Risks associated with scaling up

Meadows and permanent grasslands on clean land predominate (55% of the total) over those under cover of woods and forests (41%) and over those under cover of permanent crops (3%) or those that are non-productive under a regime single payment scheme (1%). Alentejo is the region with the largest area of permanent meadows and grasslands, with about 66% of the national total (1.27 million ha) and the Azores are the region with the highest occupation of the agricultural area used by meadows and permanent grasslands (80% of the agricultural area used).

Across the country, except for the Azores, poor grasslands predominate – i.e., natural/spontaneous grasslands not fertilized or sown – representing, on average, 73% of the total surface of meadows and permanent grasslands. In the Azores, the weight of poor grasslands does not reach 10%, the remaining 90% corresponding to sown meadows or improved natural grasslands (by fertilization or introduction of improved/selected species). Alentejo is the region with the largest area of temporary meadows (56% of the national total) and forage crops (37% of the total). It is followed in importance by the region of Entre Douro e Minho, with 10% of temporary meadows and 19% of forage crops.

Adding the area of meadows and permanent pastures with that of temporary grasslands and forage crops, we obtain a value of 2 451 329 hectares (67% of agricultural area used) dedicated to animal feed, that is, 2/3 of the Portuguese territory is occupied by these agricultural crops. Despite the current importance and the increase in area recorded in recent decades, because of the change in agricultural policies that led to a decrease in arable crop areas, in particular of cereals, and to an increase in the number of livestock in grasslands, namely in the number of cattle in extensive regime, the expected positive impact on the increase in livestock production did not occur, for several reasons.

On the one hand, because the area that increased from permanent grasslands was mainly poor grasslands, whose productive potential is incomparably smaller than that of a sown/improved meadow (400 Forage Units/ha against 2000 Forage Units/ha, on average), and on the other hand, because the meadow mixtures used in the meadows (permanent and temporary) or the forage mixtures used were not the best ones due to lack of information or experimentation.

4.3.8 Research gaps

In the near future, the Portuguese Society of Pastures and Forages will continue to strive for recognition of the important role that grasslands and forages can play in national animal production and the need to articulate efforts to produce and spread more knowledge about meadows and forage production as a guarantee of cheaper, higher quality and more sustainable animal productions.

In addition, research and experimentation work is needed to determine the best varieties and mixtures for each edaphoclimatic combination. There is also a lack of studies on the response to production factors (e.g., fertilization, irrigation, etc.) and on management, to be able to advise livestock producers and prepare manuals on good practices, which can serve as guides for the good use of these productions by the animals.

4.4 Forests and other land uses

4.4.1 Introduction

Portugal is covered, in about 35% of its territory, by forest. In addition to its economic, environmental and social value, it supports important economic sectors downstream, such as, the wood and cork industry, or the uniqueness of biomaterials for the green economy, forests are providers of goods and services to society, such as carbon sequestration, landscape creation, regulation of the hydrological cycle, combating desertification or preserving biodiversity.

There is a consensus on the need to create a forest for the future that is more orderly, biodiverse and resilient, combined with an agricultural, agroforestry and silvopastoral mosaic, capable of providing various environmental services and sustaining the economic activities associated with them, in addition to significantly reducing the severity of the burned area. In order to consolidate the process of fighting fires, it is necessary to reinforce the forest policy, which is a crucial asset to ensure the sustainability of the territory and for the future.

In the forests, a reduction in the annual average burned area should be given prominence, through improvements in land management and planning and greater investment in the management of stands, in fire prevention and fighting. New afforestation and reforestation are mostly implemented with production species (e.g., cork oak, pine and eucalyptus) or with protection and conservation species (e.g., native hardwoods), depending on the scenario considered. Also, in the context of the definition and implementation of investment support policies, it is recommended to reinforce the distribution of support for ecosystem services and the maintenance of forest biodiversity.

4.4.2 Policy context

The Portuguese forest is biodiverse, no species have dominance, all occupy less than 1/3 of the forest area, which is 72% covered by autochthonous plants. Forest policy must be oriented towards conservation and environmental sustainability, bearing in mind that the forest is also a source of economic wealth, with its forestry-industrial ranges, in particular pine, cork oak and eucalyptus. The essence of forestry policy in Portugal must be based on a symbiosis between the conservation forest and the production forest, with the priority being conservation, environmental sustainability and the minimization of fire risks. For this to happen, it is necessary to reduce unmanaged and abandoned territories, with scrubland and uncultivated land representing about 16% of the territory.

Forests and other land uses will experience improvements in forest management and consequent increases in average productivity, the rate of new afforestation (e.g., expansion of the forest area from other land uses) and the expansion rate from other land uses, with more productive and better adapted varieties and increasing the density of production or protection of species. On one hand, there will be a large reduction in the burned areas from an average of about 164,000 ha/year between 1998 and 2017 to 70,000 ha/year by 2050 (i.e., a 60% reduction). There will also be a better management of the use given to these areas after the fire, ensuring smaller total areas affected by fires, considering the suitability of the species used in reforestation, reducing deforestation caused by fires (forests converted to scrub) and making greater use of fire prevention techniques, including increasing the use of small ruminants to reduce the combustible material. On the other hand, there will be an increase in the rate of new afforestation to 8 000 ha/year (expansion of the forest area for other land uses) and a decrease in the rate of expansion of other land uses, particularly in urbanized areas, flooded dams and scrubland.

98% of the national forest is private. In order to improve forest governance and reformulate the equation of owners' income, it is necessary to incorporate remuneration for ecosystem services through appropriate forest policy instruments. The remuneration of the multiple goods and services provided by the forests will not only promote their protection, but may also constitute a complementary form of income for the forest owners, allowing the return on their investment.

4.4.3 Current land use and potential land-use competition

The component of land uses associated with forest occupation are normally large carbon sinks. This is how, in 2015, forest lands obtained a net sequestration of 11 $MtCO_{2eq}$. However, in the Portuguese case, this carbon sink potential is greatly affected by the impact of rural fires, which reveals itself directly in net GHG emissions when they are large fires, and indirectly in decisions to maintain or change the land use, by the farmers. The main factors for this change were changes in land use patterns over time and the introduction of policies to increase reforestation, improve the system for preventing and fighting forest fires (introduced after the great fire seasons of 2003 and 2005) and the introduction of incentives for carbon sequestration in agricultural and pasture soils. The fire had a high inter-annual variability due to changes in weather patterns from year to year, with a record high value of 546 kha of burnt area in 2017 (5.9% of the country). The Forest and other land uses sector changed from a net emitter in 1990 (1.2 $MtCO_{2eq}$) to a carbon sink in 1992. This situation was again reversed in the 2003 and 2005 due to the severe forest fires in recent years. In 2017, this sector returned to being a net emitter, with a total of 7.2 $MtCO_{2eq}$, representing 9% of the total country’s emissions of for the reasons previously mentioned. Excluding that year, the average over the last decade would be -10 $MtCO_{2eq}$.

The net total of emissions and carbon sinks is therefore currently 60 $MtCO_{2eq}$, and this is the order of magnitude that will have to be reduced by 2050 to achieve carbon neutrality. Therefore, it will be necessary to ensure a large reduction in burned areas, from an average of about 164,000 ha/year between 1998 and 2017 to 70,000 ha/year by 2050 (i.e., a 60% reduction), to be careful about the use given to these areas after the fire, ensuring smaller total areas affected by fires, considering the suitability of the species used in reforestation, reducing the deforestation caused by fires (forests converted into scrubland) and making greater use of fire prevention techniques, including increased use of small ruminants to reduce combustible material. On the other hand, there is a series of actions that will allow improvement of forest management and achieve consequent increases in average productivity, such as improving management and increasing fire prevention, using more productive and better adapted varieties and increasing density, of either production or protection species.

4.4.4 Climate risks & sensitivities

Forests, in addition to being considered one of the greatest natural heritages, are considered the great precursors in the mitigation of climate change. On the other hand, one of the most notorious consequences of climate change is the occurrence of extreme temperatures, which, if very high, increase the probability and intensity of fire occurrence. Fires are one of the worst scourges facing the national forest, and consequently, in addition to the impacts on populations, the economy and biodiversity, the carbon sequestration service is also heavily penalized. Thus, if climate change penalizes the provision of carbon sequestration services by forests via combustion, there is a vicious cycle between climate change and carbon sequestration, as it is one of the main solutions in combating change climate.

The effects of climate change with extreme events characterized by very hot and very dry climates and with deviations in relation to precipitation have culminated in large forest fires in Portugal. The impacts of climate change should be taken into account in mitigation options, notably as regards future water availability, heating and cooling needs and the risk of rural fires. In this regard, it is also particularly important to note that the determining factor in forest carbon sink capacity - a decrease in the annual average burned area - will be hampered in a scenario of worsening of the effects of climate change. In order to reduce the climate change effects in the Portuguese forests, the management and planning of the territory must be improved to reduce the average annual burned area. In addition, there must be a greater investment in the management of plots, especially in the prevention and fighting of fires. Active forest management is crucial to defend the environment, protect biodiversity, fight fires and minimize the advance of desertification, which is one of the great problems facing the country.

4.4.5 Economic implications

The challenge for the forestry sector in Portugal lies in the ownership structure, which is extremely fragmented, and the attractiveness and income of owners, only possible with investment in the conversion of diversified landscapes capable of promoting the well-being of local populations and communities, in addition to making territories more resilient to fire risk. Portugal is one of the European countries potentially most affected by climate change and therefore it is necessary to create a more adapted territory.

4.4.6 Co-benefits and trade-offs

In the forest sector, the increase in active afforestation, the promotion of more efficient forestry practices in the use of resources and risk management, and the valorisation of ecosystem services, leverage and sustain a growing role for the bioeconomy, with an impact on carbon retention and on the net balance of emissions. Future productivity gains may arise from better forest management practices and less fire losses, as forest area expansion is expected to be limited by 2050, which means a reduction in forest area relative to 2015.

The forest sector is a value chain that already has a high degree of circularity, and forests play an inevitable role in achieving carbon neutrality. Thus, it can be seen that investment in forests to increase biological carbon sequestration could lead to gains of over 40% by 2050 (compared to a non-circular scenario).

4.4.7 Risks associated with scaling up

The tendency of the forest area is to remain relatively constant until 2050. However, it is expected an increase in the rate of new afforestation, i.e., expansion of the forest area to other land uses of 8.000 ha/year due to the inevitable rural depopulation.

4.4.8 Research gaps

Not applied.

5. Conclusions

In the last decade, Portugal presents a decreasing trend of GHG emissions, and it has the objective to reach neutrality emission until the end of 2050 with an emission reduction trajectory from 85% to 90% by 2050 compared to 2005.

The GHG emissions are mainly due to biomass burning, where rural fires play an important role in GHG emission values due to poor management and planning, and to the extreme weather events that are occurring more frequently. Hence, Portugal is investing in afforestation and reforestation with low-growing species and protection against fire (cork oak and stone pine), reducing fast-growing and fire-susceptible tree species (e.g., eucalyptus, maritime pine and other resinous trees) as they are more resistant and less vulnerable in case of drought or cold or heat wave and consequently mitigate fire prevention.

In croplands, the mineral fertilization will be replaced by organic fertilization to reduce the total quantities of fertilizers used and to increase the organic matter content cover crops will be used. All these measures will lead to total reductions of -177 ktCO_2eq in 2030, -331 ktCO_2eq in 2040 and -639 ktCO_2eq in 2050.

Agroforestry systems, such as, the Montado which is a very high nature value system, and a hotspot of biodiversity has a CO_2 retention associated with cork oak forests around five million tons/year (5% of total CO_2 emissions in the country). In these systems there has been management towards the protection and natural regeneration and the planting of cork oaks and holm oaks to preserve and increase the retention of CO_2. Montado soil is poor and therefore farmers are putting low soil inputs correction and planting biodiverse pastures with the correct balance between grasses and legumes, to increase the soil organic matter and the CO_2 retention. These grasslands uptake more carbon than spontaneous natural grasslands with an estimated carbon sequestration factor of 6.48 tCO2.ha-1.yr-1 for a period of 10 years.

The highly qualified Portuguese farmers ("front runners") use of precision agriculture (PA) to implement sustainable practices and exploitation of resources considering the European Policies (e.g., Green Deal and Farm to Fork) and consumer sustainable concerns, translate effectively in the reduction of GHG emissions through practices of environmental protection, mitigation of climate change and combating desertification. With the national projections of CO_2 emissions from agriculture of 29%-34% by 2050, PA thus emerge as a solution to reduce agriculture total emissions and increase carbon sequestration by eco-regime payments, that will integrate the 1st and 2nd Pillars of the CAP post-2020, to farmers when they consider the environment, climate change and the country in their practices.

Climate changes (i.e., temperature and precipitation) is affecting crop growth, development and productivity, in the same way that affect the grassland productivity. Global warming, as well as pests, diseases and weeds, are affecting the phenology and the increase of CO_2 on the photosynthetic efficiency of cereals and fruit trees. However, climate change will affect differently Portugal due to the very marked thermal gradient and geographic characteristics of the North and South regions.

6. References

Alvarenga, A., Marta-Pedroso, C., Santos, J., Felício, L., Serra, L. A., do Rosário Palha, I. M., Palha, M. do R., Sarmento, N., Vieira, R., Santos, S., Oliveira, T., Sousa, T., & Domingos, T. (2017). Towards a carbon neutral economy how is Portugal going to create employment and grow? *MEET2030, Business, Climate Change and Economic Growth*, 109.

Fraser, A. (2019). Land grab/data grab: Precision agriculture and its new horizons. *The Journal of Peasant Studies*, *46*(5), 893–912.

Loures, L., Chamizo, A., Ferreira, P., Loures, A., Castanho, R., & Panagopoulos, T. (2020). Assessing the effectiveness of precision agriculture management systems in mediterranean small farms. *Sustainability*, *12*(9), 3765.

Portuguese Environmental Agency. (2019). *PORTUGUESE NATIONAL INVENTORY REPORT ON GREENHOUSE GASES, 1990—2017*.

RNC2050. (2019). *Roadmap for carbon neutrality 2050 (RNC2050). Long-term strategy for carbon neutrality of the Portuguese economy by 2050.*

Schrijver, R., Poppe, K., Daheim, C. (2016). Precision agriculture and the future of farming in Europe. In: Scientific Foresight Study. European Parliamentary Research Service, Brussels, Belgium.

Sishodia, R. P., Ray, R. L., & Singh, S. K. (2020). Applications of Remote Sensing in Precision Agriculture: A Review. *Remote Sensing*, *12*(19), Art. 19.

Teixeira, R., Domingos, T., Costa, A., Oliveira, R., Farropas, L., Calouro, F., Barradas, A. M., & Carneiro, J. (2011). Soil organic matter dynamics in Portuguese natural and sown rainfed grasslands. *Ecological Modelling*, *222*(4), 993–1001.

ANNEX III

OVERVIEW OF INPUT TABLES FOR SIMULATION MODELLING PER COUNTRY

This project has received funding from the European Unions' Horizon2020 Grant Agreement No 869367

3. Portugal

3.1. Qualitative storylines by identifying measures and actions from interviews for each LMT scenario

Country PORTUGAL and SPAIN LMT 3: Forests and Agroforestry (Montado (Portugal) and Dehesas (Spain))

	1. Wishes of the future for the LMT: include timing	2. How to achieve the wishes • Who pays? • Who implements?	3. Target/Actions • Policies, strategies, projects
Scenario 1: "High Natural Value System" **Stakeholder representations:** farmers, forest and agroforestry producers, forestry associations, industry, polluting companies	• Valuing the natural capital of agro-forestry companies by creating good practices in: i) carbon balance; ii) biodiversity; iii) landscape; iv) resilient territories (fire risk reduction); and v) social value, by 2050	• Polluting companies, industry pay by purchasing CO_2 credits from farmers/forestry producers • Implemented by companies like AgroInsider and government based on the decree-law that creates and promotes the development of a nationwide voluntary carbon/biodiversity market • CO_2 credits	• Actions start now with pilot projects • Regulations on voluntary carbon market in order to create trust • Montado/dehesa carbon credits certification • Fire risk reduction
Scenario 2: " No change or loss" **Stakeholder representation**s: farmers, forest and agroforestry producers, forestry associations, industry, polluting companies	• Accelerated natural capital degradation due to production systems intensification and climate change pressure on natural resources by 2050	• The degradation will be paid by European tax payers • After degradation, natural capital are difficult and sometimes impossible to completely recover	• Changes in legislation risks, for example eliminating the need for environmental and social companies compensations (e.g., ESG) • Not promoting the enhancement of the

	• Less resilient territories by means of high fire risks and social territory abandoned and desertification	• Government funds subsidies will be used to replace and monetize losses putting more pressure on prices of goods	territory through the preservation and protection of biodiversity and natural capital

Country Portugal LMT 1: Cropland

	1. What are the wishes of the future for the LMT • include timing	2. How to achieve the wishes • How much does it cost? • Who pays for the cost? • Who implements?	3. Actions • policies, strategies, projects
Scenario 1: "Sustainable agricultural practices" **Stakeholder representations:** Farmers, consumers, food retailers	• Soil and water conservation by means of precision agriculture practices to reduce carbon emissions and enhance carbon sequestration • reducing the use of synthetic fertilizers particularly urea nitrogen type • direct seedling and cover crops to improve water conservation by 2030	• Supporting financially farmers to do good practices • Precision agriculture consultancy to monitor and inspect the production systems to optimize CO2-biodiversity-Soil-Plant-Water processes • Farmers being trained on how to implement the sustainable agricultural practices	• Actions started due to the Green deal and Farm to fork European objectives • Climate change is driving the adoption of sustainable agricultural practices for the efficient use of water, especially in drier regions (e.g., South of Portugal).

Country Portugal LMT 2: Grassland

	4. What are the wishes of the future for the LMT • include timing	5. How to achieve the wishes • How much does it cost? • Who pays for the cost? • Who implements?	6. Actions • policies, strategies, projects
Scenario 1: "Biodiverse grasslands" Stakeholder representations:	• Swon biodiverse pastures rich in legumes and grasses can increase three times more the organic matter that can rapidly grow in the soil and hence to increase carbon sequestration and promote floristic biodiversity to pollinators by 2050 • Soil pH correction to promote biomass yield (e.g., in Montado/Dehesa) by 2050	• Supporting financially farmers to sow biodiverse pastures rich in legumes and grasses and to correct soil pH • Farmers are the ones who implement these practice	• According to the trajectories for carbon neutrality of the Portuguese economy and Circular Economy by 2050 • To reduce the use of nitrogen fertilizers and its environmental impact, increase the production of biomass and soil fertility and contribute to an increase in the volume and quality of dairy/meat production • To reduce production costs and consumption of concentrated feed and raw materials needed for its manufacture

3.2. Quantitative storylines: pace of implementation for each LMT

	Current situation (baseline)	SCEN-" High Natural Value System" SH perspective:		SCEN-"No change or loss" SH perspective:	
Year	Now (provide sources)	2030 (change relative to the current situation) (provide sources)	2050 (change relative to the current situation) (provide sources)	2030 (change relative to the current situation) (provide sources)	2050 (change relative to the current situation) (provide sources)
LMT 3: Forest and Agroforestry (Montado & Dehesa)	In decline, high animal load (Pinto-Correia et al. 2013); Loss of 1 tree ha/year in the Iberian Peninsula due to climate change (3 M trees in the Iberian Peninsula), ≈9 M ton/year of CO_2.	Achieve maintaining the current state by reducing the rate of degradation	Recover the stock of CO2 by the densification carried out 40 years ago in an annual growth of 9 M ton/year of CO_2. Burned area of 50 thousand ha per year Creation of new forest in non-forested areas per plantation of 410 thousand ha of new plantations by 2050	If climatic pressure increase and production systems intensification are kept, degradation can be doubled reaching 18 M ton/year of CO_2.	If climatic pressure increase and production systems intensification are kept, degradation can be triple reaching 27 M ton/year of CO_2. Plant trees that are more adapted to climate change.
LMT 2: Grassland	Poor grasslands predominate – i.e., natural/spontaneous grasslands not fertilized or sown –	20% of farmers plant biodiverse pastures	an increase, by 2050, of biodiverse pasture areas corresponding to 50% of the areas		

	representing, on average, 73% of the total surface of meadows and permanent grasslands.		occupied by meadows and permanent pastures improved and sown on clean land Net sequestration of 0.76 Mt in 2050		
LMT 3: Cropland	Some PA front runners in Portugal implemented sustainable practices and exploitation of resources considering the European Policies (e.g., Green Deal and Farm to Fork) GHG agriculture emissions to total national emissions of 9.8 % in 2017; Organic farming area represents 6% of the agricultural area*	Increase in productivity and a more efficient use of resources Increase carbon sinks with low GHG emissions from agriculture of 6.8 $MtCO_2eq$ in 2015 (83% of animal sector and 17% of mineral fertilisers, lime correctors and crop residues not removed from agricultural lands)	emissions from agriculture will have a weight in national emissions between 29% and 34% by 2050 an increase, by 2050, of direct sowing areas corresponding to 50% of the areas occupied by rainfed cereals and maize -1.5%/year of consumption per hectare of synthetic nitrogen fertilizers		

* Organic farming has low impact per unit area but is limited in nitrogen.

Organic farming needs agroecological and circular economy improvements to be feasible globally. (https://www.sciencedirect.com/science/article/abs/pii/S0959378021000923)

References

Pinto-Correia, Teresa, and José Mira Potes. "Livro verde dos montados." (2013).