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Introduction

Climate change represents the greatest environmental challenge humanity has ever faced, whose effects today seem to be irreversible.

The impacts of climate change, amplified by the increase in average temperature and by the frequency and intensity of extreme weather events, significantly affect the environment and people, compromising the availability of resources and representing a threat to economic stability.

Agriculture is one of the most affected and vulnerable sectors and, given its multifunctional role (e.g. meeting food needs, preserving the biodiversity of the environment and strengthening the resilience of territories), plays a crucial role in mitigation and adaptation strategies. At the same time, agriculture is significant anthropic activities in terms of direct and indirect greenhouse gas emissions (GHG) (around 10% of the gross emissions in the EU) due to agricultural practices, livestock and land use change.

The impacts of climate change on agriculture are unevenly distributed in the various geographical areas, being highly dependent on weather and environmental conditions as well as on the adaptability of natural systems, infrastructures and local economies.

The Mediterranean region, as also highlighted by recent scientific studies, is one of the most vulnerable areas, in which the processes of desertification and erosion caused by climate change are hastened by a massive use of agricultural land and poor irrigation practices contributing to the reduction in the availability of water and soil resources.

In such a context, agriculture is facing four main challenges: (i) becoming moreresilient and adapting to climate change, (ii) reducing its impact in terms of GHG emissions and soil degradation, (iii) increasing its carbon sink potential, (iv) providing sufficient and healthy food to meet the growing demand of the population. This requiresa transition from current models of intensive production to new models based onsustainable resource management promote organic agriculture and sustainable agricultural practices to limit erosion, improve soil quality, increase soil nutrients and reduce water and energy needs. To this issue, many international, national and local programs have been set to promote the changes towards a sustainable agriculture.

The adoption of a holistic approach is therefore essential to effectively represent the main variables (energy, water, environment, food and soil) and their interrelationships, exploit the complex interconnections between them and the associated phenomena, reduce risks identify feasible strategies for sustainable resource management based on integrated policies.

The "Nexus Thinking" and its multi-sector framework represent a privileged approach to respond to the sustainability challenge and enable an effective management of resources for the achievement, among others, of the Sustainable Development Goals (SDG), the Paris Agreement targets and the European climate neutrality objective. Concepts of the Nexus Thinking were successfully applied in different contexts (e.g, energy, minerals, etc.) and regions, from developing countries to advanced economies.

Many examples in literature underline the increasing importance of this integrated approach to the Water-Food-Energy (WEF) challenge and different models and tools have been used to assess WEF interactions ranging from economic to technological and geographic information systems (GIS). However, there are still gaps that need to be filled in the operational application of the nexus concept to decision making.

The above context constitutes the background and the motivation for this thesis, which main objective is to advance the understanding of the relations of Water-Energy-Food nexus and to develop a modelling platform focused on the agricultural system. A tool that integrates the nexus concept into a framework typically used to support decision-making when different competing goals are to be achieved.

Specifically, in this work the WEF nexus approach has been integrated into the IEA-TIMES framework by developing an innovative land use driven model - the TIMES Land-WEF model, which ensures an optimal management of resources of the entire agricultural system in a circular economy perspective.

The TIMES- Land-WEF model was validated in the Basilicata Region, a selected area of Mediterranean Europe, in order to evaluate the robustness of solutions under different conditions, namely to determine the effects of climate change on agricultural production and performing and assessment of the Farm to Fork strategy of the EU Green Deal.

The thesis is structured as follows:

Chapter 1 presents the framework in which the research has been developed, highlighting the implications for agriculture and its main variables, water, energy and food both in terms of environmental and policy effects, with a focus on EU energy and agricultural policy framework.

Chapter 2 presents a literature review of models and tools for analyzing agricultural and energy systems with reference to the Nexus approach and its applications.

Chapter 3 describes the IEA-ETSAP methodology for energy system analysis and its application for the development of the TIMES Land-WEF model (technical assumptions, data requirement, the pre-processing procedure for the implementation of the model data input and the results of the calibration to the statistical base year data).

Chapter 4 describes the setup of the climate and policy scenarios to be analyzed by the TIMES Land-WEF model, based on the main assumptions of IPCC climate scenarios (assuming a 2 degrees increase in global average temperature), and the EU energy and agricultural framework policy, according to three evolutionary hypotheses: (i) Business as Usual, (ii) Climate and (iii) Agricultural Policy.

Chapter 5 presents the main results of the scenario analysis highlighting the outcomes in terms of use resources, pesticides and fertilizers, crop distribution, conventional and organic agricultural practices, with conclusive remarks.

Chapter I *Climate Change and Sustainable development Challenges*

1.1 The Background

The latest report by the Intergovernmental Panel on Climate Change (IPCC[1]) confirms a clear human responsibility for climate change, as anthropogenic activities are among the main contributors to greenhouse gas emissions and provides new estimates on the trend of global warming for the next decade.

Scientists estimate that it will be impossible to limit global warming to 1,5 °C or even 2°C, as established by the Paris Agreement, without irreversible consequences, unless thereis a rapid global decline in greenhouse gas emissions over the next decade (IPCC, 2021).

In particular, changes in precipitation cycles and temperatures and the increased frequency of extreme weather events such as droughts and floods, will directly and indirectly cause significant changes in water, energy and land availability with consequent effects on the agri-food system, future economic development and well-being of populations. Sudden changes in climatic conditions at such a rapid rate also contribute to jeopardize food security, quality and access to food (Arora, 2019).

It must also be considered that the world population is expected to reach 9.7 billion by 2050, which would increase the pressure on agricultural land to meet the growing food demand already affected by the impact of climate change (UN, 2019).

One of the main consequences is the use of intensive agricultural practices including the unprecedented use of chemicals for agriculture, livestock production (for meat and other sources of income), exploitation of water resources, aggravating the situation with the release of GHG (due to agricultural activities) and with consequent pollution of natural resources (Adewale, 2018).

[1] The IPCC is a UN body for assessment of climate change. Established in 1988 by the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO), over the time, the work of the IPCC has been successful in terms of developing public awareness of the problem and putting climate change on the political agenda. Its main strateegy is to enable political action by providing a scientifically established definition of the climate issue, including its consequences and measures for adaptation and mitigation.

Forests act as a sink for the increasing amount of CO_2, but the uncontrolled rate of deforestation (mainly for agriculture) has affected significantly the natural processof the carbon cycle. These has increased the concentration of GHG in the atmosphere, inducing a number of adverse climate effects that have a major impact on agricultural production (Bajaj, 2022). These also results in a very high rate of soil degradation, causing an increasing desertification and nutrient-deficiency of soils (Brevik, 2020).

Sustainable farming practices, such as crop rotation or soil cover with organic matter, help reduce the impacts of climate change. Moreover, these practices are included in a broader sustainable development program. The 2030 Agenda for Sustainable Development, signed by the governments of 193 Member Countries of the United Nations, represents a global development guideline for progress in a perspective of sustainability by interconnecting environmental, economic and social issues (UN, 2015) and lays the foundations for an integrated multidimensional approach to address resource management and climate change by identifying 17 Sustainable Development Goals (SDGs). This policy context underlies the 'nexus approach', which pushes policy makers to foster trade-off and interactions between individual SDGs in order to exploit synergies and reduce risks (Liu,2018).

1.1.1 The trade-offs between agriculture and climate change in Mediterranean Europe

Agriculture, a key sector of sustainable development, but it is also one of the most affected sectors by the impacts of climate change. Although the effects of global warming (such as the increase of temperatures) can cause increased yields of some crops, the occurrence of the extreme weather events (drought, hail, floods,and strong winds), the water scarcity, and thermal stress can cause irreversible damage tothe whole agri-food system and affect soil availability. Therefore, the effects of climate change on the agricultural sector, largely with negative impacts, are not uniformly distributed differing in several geographic areas.

Although climate adaptation is an intrinsic characteristic of the primary sector, the magnitude, uncertainty and speed of ongoing and expected climate change make it necessary to increase its adaptability, reduce its impacts, but also take advantage of the opportunities deriving from changed climatic conditions (Agovino, 2019).

In general, agricultural production in northern Europe could increase thanks to higher temperatures and longer growing seasons, which will allow for growing new products.

On the other hand, in southern Europe, a highly vulnerable area most affected by climate change phenomena, extreme weather events and scarcity of water resources will negatively affect agricultural production and favour the spread of agricultural pests with the proliferation and diffusion of new species of insects, plant pathogens, parasites and weeds (Cramer, 2018).

In particular, the decrease in annual rainfall is accompanied by an increase in the intensity of rainfall with consequent degradation of agricultural land and a substantial decrease in the crop yields, which for the year 2010 amounted to an average loss of about 3.24 t/ha per year (EEA, 2019).

With the increase in global temperature of two degrees, the yield of wheat in southern Europe, where it has been grown for thousands of years, will decrease by 12%, while in northern Europe it will increase by 5 %. In addition, due to the great stress generated by heat and water scarcity o during summer, it may be necessary to grow some seasonal products during the winter (Aguilera, 2020).

Furthermore, historical droughts trends in Europe indicate that the frequency and severity of droughts in the Mediterranean area increased over the period 1950-2015 (Spinoni, 2017). These phenomena are already affecting the production of arable crops and animal feed in Europe, which can have an impact on farmers' income (Fraga, 2016). Moreover, by the end of the century drought will cause an increase in the demand for irrigation water in most of the regions in Europe (Wada, 2013) and an increase of the demand for water from different economic sectors (e.g., agriculture, industry, civil society).

In several European southern countries, human-induced soil degradation (to which agricultural activities contribute strongly) is accelerated by climate change, whichfosters soil erosion and desertification processes. This affects in particular the availabilityof soil for permanent crops (e.g. vineyards and olive trees, followed by arable land) whichshowed the highest loss rate (Panagos, 2015; Eurostat, 2021).

The impacts caused by climate change on agricultural ecosystems and agricultural production will affect, in turn, quantity and quality and price of products and, consequently, business models, agricultural income and food prices (FAO, 2016).

Also considering the worsening working conditions of the farmers, in southern Europe, the climate crisis could be a further driving factor of the abandonment of agricultural land, endangering the natural habitats and increasing the risk of fires (EU, 2019).

This overall situation could cause permanent damage to southern Europe economic growth, widening the already existing gap between northern and southern Europe and potentially undermining the stability of the EU (Dinam, 2019).

Therefore, in the coming years in agriculture new and important problems due to climate change will have to be faced, including: variability of agricultural yields; agricultural pest problems; dry summers, with higher water requirements for intensive crops; soil erosion; salinization of water resources due to sea level rise (EAA, 2019).

If on the one hand, as just stated, agriculture is particularly vulnerable to the impacts of climate change, on the other it is necessary to consider the key role of this sector in the reduction of greenhouse gas emissions and in mitigation strategies (both through greater efficiency of land and livestock both through the action of carbon storage in soils) (Loboguerrero, 2019).

Indeed, agriculture is a major source of greenhouse gas emissions (around 10% in the EU) (EEA, 2019). The most important pollutants from this sector, methane (CH_4), nitrousoxide (N_2O), ammonia (NH_3) and primary particulate matter (PM_{10}) are due to livestockfarming (production and processing of feed, enteric fermentation and decomposition of manure). Furthermore, indirect emissions associated with land use change and agricultural practices (through inputs such as fertilisers, pesticides, fuel, machinery and electricity) play a relevant role (Tubiello, 2019). Therefore, climate change mitigation actions in the agricultural sector involve, on the one hand, a direct reduction of greenhouse gases and, on the other, a reduction of emissions through more efficient management of livestock and land (Roe, 2019).

The transition from the current models of intensive production, widely diffused and consolidated, to new practices based on the sustainable management of resources is therefore a priority (Skinner, 2014). In this perspective, several programs at global (FAO), EU, national and regional level provide a framework for action at farm level (EEA, 2019).

As an example, organic farming models (which exclude the use of chemical fertilisers) can reduce anthropogenic emissions, as they favour the storage of organic carbon in soils increasing their natural fertility. This contributes also to improve water storage capacities and increase resilience against droughts, and floods (Meemken, 2018).

Improved irrigation efficiency, rainwater harvesting and water reuse reduce water abstraction and can help improve water quality, promote carbon storage in soils and higher yield and protect ecosystems and soil biodiversity (Malek, 2018).

Furthermore, nature-based solutions, i.e. agricultural practises attentive to natural cycles, based on crop differentiation, crop rotation and the planting of alternative species within the same plot contribute to improve the quality of the soil, limiting erosion and increasing the presence of nutrients in the soil (Roesch-McNally, 2018).

Limiting tillage (no tillage or minimum tillage) can also help making soil more resistant to the erosion process by promoting changes in the soil structure and the position of soil organic matter and crop residues, increasing noticeably soil organic carbon and reducing the energy consumption of agricultural machinery (Li, 2020).

Another example is the introduction of buffer strips, an action that consists in placing trees and bushes in areas a few metres wide along the cultivated fields, which, by subtracting land from agricultural production, contribute to reduce water and winderosion (Eagle, 2012)

In conclusion, agricultural practices should be aimed at contributing to resilience and adaptation to climate change, reducing the impact of processes in terms of emissions and soil degradation, providing sufficient and healthy food to fulfil the increasing demand, ensuring well-being of population. The achievement of these objectives should be supported by an efficient and integrated management of the three main systems involved (water, energy, food) and their resources, taking advantage of the improvement of the agricultural sector as an opportunity to contribute to environmental and socio-economic sustainability.

1.1.2 The role of the agri-food sector and the Water-Energy-Food Nexus

Agriculture is one of the pillar of the sustainable development strategies and plays a key role in achieving many of the SDGs objectives, from nutrition to health, conservation of resources, the fight against climate change and poverty. In this perspective, it is urgent to change from a system based on the intensification of the use of resources to another based on the improvement of the total productivity to increase the efficiency of agricultural processes, increase productivity and reduce its environmental impacts in terms of emissions, soil erosion and biodiversity loss, contributing to preserve natural resources (Struik, 2017).

The three fundamental components of the nexus (energy, water and food) and their complex interrelationships are the foundation in the definition of management strategies being difficult to model due to the many variables and phenomena involved (Nazmul Islam, 2020).

As well known, water is required both in food production (e.g., crops, livestock) and energy (e.g., hydroelectricity, cooling water). At the same time, energy is needed for food production (e.g. energy for chemical and mineral fertilisers, transport and storage of food) and for water supply (e.g. extraction, purification, desalination, pumping, etc.).

Agriculture, a major player in food production, uses a significant share of water (over 70% of all water consumption globally) (UN, 2018) and energy (about 30% of the total energy demand) (IRENA, 2021) affecting the availability of water resources through soil degradation, changes in runoff and disruption of groundwater discharge.

In addition, the area available for agricultural activities also competes for a share in the production of electricity generation from fossil and renewable sources, both in terms of the area required for the installation of power plants and the impact of the related activities (e.g., mines dams and watercourse management, biofuel production, etc.).

In particular, cultivation of biofuels, which has a high profitability per hectare and, in many cases, benefits of public incentives, causes an excessive exploitation of territories, indirectly generating a potential pressure on the prices of food crops and increasing competition between land use and water consumption to produce biofuels or food. Rulli et al. (2016) estimated that the world production of biofuel exploits 4% of the land and water used for agriculture, corresponding to an area sufficient to feed about 280 million people if used for the cultivation of food crops.

The inextricable links between these three critical domains require a properly integrated approach to ensure water, energy and food security as well as sustainable agriculture production.

The Water-Energy-Food (W-E-F) nexus, schematized in Figure 1.1, is a key conceptual approach for sustainable development and allows modelling and analysing the complex interactions between water, energy and food systems.

The adoption of a nexus perspective allows to enhance synergies and reduce potential conflicts, identifying and managing trade-offs and strengthening intersectoral integration in order to ensure a more efficient and sustainable use of resources not only in the agricultural sector (FAO, 2014).

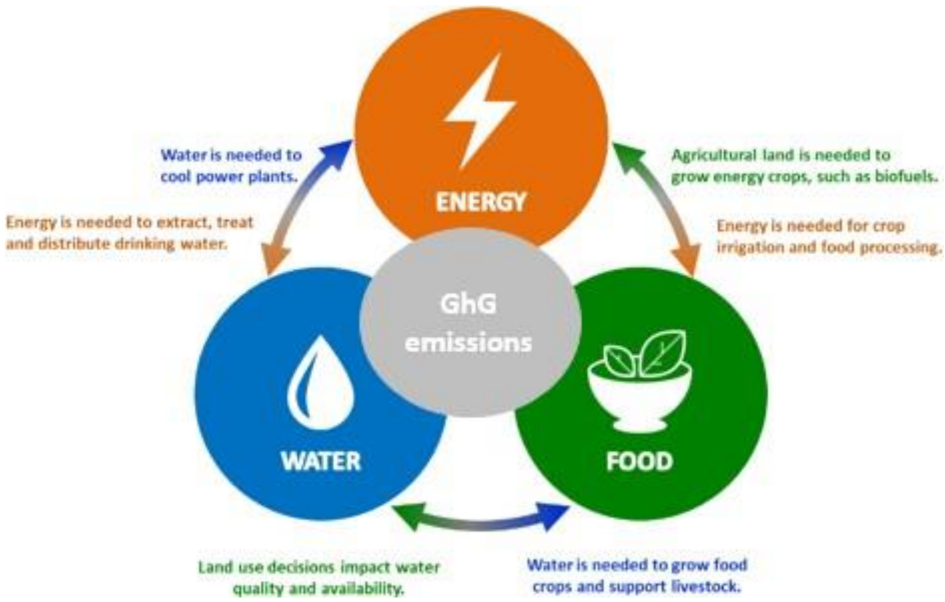

Figure 1.1 Representation of Water, Energy, Food Nexus.

Since 2011, when it was first brought to the attention of the institutions in the opening report of the World Economic Forum (Hoff, 2011), the Nexus approach has assumed a central role for understanding and modelling the complex interactions between the natural environment and anthropogenic activities allowing a more coordinated management of the three fundamental resources systems (Albrecht, 2018), being utilised both in academic researches and by international organizations (e.g. FAO, CE, UNECE, WWF and others).

1.2 The EU climate and agriculture policy framework

1.2.1 The 2030 climate and energy framework and the European Green Deal

The 2030 climate and energy framework highlights the necessity of coordinated efforts by all sectors for the achievement of the key targets for 2030. In particular, the greenhouse gases reduction target should be achieved both reducing emissions and increasing removals, including land use, land use change and forestry (LULUCF) contribution as stated by the Land use, land use change and forestry Regulation. EU Member States must be therefore "neutral" under the so-called no-debit rule ensuring that accounted greenhouse gas emissions from land use, land use change and forestry are balanced by at least an equivalent accounted CO_2 removal from the atmosphere in the period 2021 to 2030 (EU, 2018b). This framework points out the critical role of agriculture and its impact on land use in climate policies. In fact, the new climate policy framework defines revised and ambitious emission targets for non-ETS sectors[2], which also includes the agricultural sector (EU, 2018a). For Italy, the reduction target for all non-ETS sectors is set at 33% less than in 2005 and 3% more than the EU forecast (MISE, 2019).

In December 2019, the EU Commission presented the European Green Deal whose overarching objective is to foster the EU becoming the first climate neutral continent by 2050. It represents a roadmap to support a clean and circular economy, promote adaptation to climate change, fight the loss of biodiversity and reduce pollution, outlining a package of measures to enable European citizens and businesses to benefit from a sustainable green transition (EU, 2019).

In light of the necessity of achieving climate neutrality by 2050, the commitment proposed as a part of the European Green Deal in September 2020 was to reduce greenhouse gas emission reduction target, including emissions and removals to at least 55% by 2030, compared to 1990 levels (EU, 2021) (National Determined Contribution - NDC of the EU and its Member States).

[2] Non-ETS is understood as a part of the domestic greenhouse gas emissions that are not covered by the European Union Emission Trading Scheme (EU ETS). Non-ETS emissions include the following sectors: transport, agriculture, waste, industrial emissions outside the EU ETS and the municipal and housing sector with buildings, small sources, households, services, etc.

By making climate change a priority, the EU Green Deal also covers all the objectives of the United Nations 2030 Agenda expressed by the 17 SDGs, underlining the need for more ambitious and integrated actions and policies in the different areas to balance environmental sustainability, economic and social and to bring about a profound economic and social transformation.

1.2.2 The Farm to Fork Strategy

The Farm to Fork strategy (F2F), an integral part of this "green" and sustainable change promoted by the EU Green Deal, finalises the policy framework in support of climate neutrality by driving a substantial transformation of agriculture over the next decade with the aim of making the agri-food system fair, healthy and environmentally friendly (EU, 2020).

The expression "Farm to Fork" is not new in EU terminology usually indicating that the food available to the consumer is safe, of high quality, respectful of animal and crop health. The new meaning emphasizes the sustainability aspect of the product, strengthening actions and measures to address climate change, protect the environment and preserve biodiversity. Therefore, it faces a system approach to the challenges related to the sustainability of food systems, recognizing the connections that bind the health of people, societies and the environment.

The EU therefore aims to reduce the environmental and climate footprint of its food system and strengthen its resilience, ensure the security of food supply in the face of climate change and biodiversity loss, lead the global transition towards competitive sustainability from producer to consumer and take advantage of new opportunities (EU, 2020).

The Farm to Fork strategy is appropriately framed in an overall system of long-term objectives relating to health and safety, food, environment, competition, international cooperation, internal market, trade. In particular, a ten-year strategy, outlines a "new decision-making level" according to which agricultural policy emerges from its condition of isolation from other common European policies (Sotte, 2021). It is developed around six macro-objectives, which concern the sustainability of food production, safety in food supply (the so-called Food Security), sustainability in the phases of the food supply chains following the agricultural one (distribution, sales, catering, etc.), the promotion of sustainable food consumption, the reduction of food losses and waste and the fight against fraud in the food supply chains. Therefore, this very broad strategy interconnects various European policies and funds, designed to address various challenges that require a systemic and complex approach expressed in some ambitious objectives to be achieved by 2030, including:

- ✓ 50% reduction in the use of chemical pesticides;
- ✓ 20% reduction in the use of fertilizers;
- ✓ Achievement of at least 25% of organic agricultural land at European level.

The achievement of these goals is based on a bottom-up approach, where the " key actors " are the farmers, responsible for the transition to sustainable production models that respect the environment and its ecosystem.

In particular, the Farm to Fork strategy contributes significantly to strengthen the orientation of the Common Agricultural Policy (CAP) aimed at promoting a progressive abandonment of intensive agriculture in favour of more sustainable cultivation techniques that preserve the quality and fertility of the soil by reducing the use of fertilizers and pesticides (EU, 2019) with a strong impact on the future planning of agricultural activities.

1.2.3 The Common Agricultural Policy (CAP)

The Common Agricultural Policy (CAP) was launched in 1962 as a policy framework for all EU countries aimed at supporting farmers and increasing their living conditions, improving agricultural production, ensuring food security, stabilizing markets while maintaining reasonable prices for consumers, promoting jobs in farming, agri-food industries and associated sectors (Pe'Er, 2019).

Since the 1990s, the Common Agricultural Policy (CAP) has embarked on a path of increasing commitment and attention to green issues and environmental sustainability, focusing on climate change, sustainable management of natural resources, protection of rural areas and landscapes, with significant impacts also on the primary sector (Cortignani, 2019).

The CAP represents almost 36% of the EU budget and is financed by two assets: the European Agricultural Guarantee Fund (EAGF) and the European Agricultural Fund for

Rural Development (EAFRD), which reflect its many facets and multiple variables, involved. The European Commission develops it every seven years, directing from top to bottom the methods of application of each agricultural policy measure (Guth, 2020).

A “greener and fairer CAP” is proposed for the Post-2020 programming cycle, which marks the shift from a CAP centred on enforcement of rules, controls and sanctions, to a performance-centred CAP. The European Commission has in fact set some general objectives, but each State will be able to adapt the policy to its national context by developing individual National Strategic Plans. The Commission will have the task of verifying that these plans are ambitious enough to allow for achieving the general objectives of the EU (EU, 2021).

The more ambitious and more result-oriented "new delivery model" will enable Member States to achieve specific EU objectives (including environmental and climate objectives) through a combination of mandatory and voluntary measures, taking into account analyses, targets and of the other regulations in force (EU, 2017).

In particular, the post-2020 CAP aims to achieve three general objectives: to promote a smart, resilient and varied agricultural sector that guarantees food security; strengthen the socio-economic framework of rural areas; strive for environmental protection and climate action contributing to the achievement of the UE environmental and climate objectives. To these it is added the transversal objective of modernizing the agricultural sector through the promotion and sharing of knowledge, innovation and digitization processes fostering their use in agriculture and rural areas.

The achievement of the general objectives is pursued through nine specific objectives, three of which, reported in the following, refer to the environmental and climate topics:

1) Contribute to the mitigation and adaptation to climate change, as well as to the development of sustainable energy;

2) Support a sustainable development and efficient management of natural resources such as water, soil and air;

3) Contribute to biodiversity protection, enhance ecosystem services and preserve habitats and landscapes.

Based on the experience of the 2014-2020 programming cycle, the operational tools were also revised in order to achieve the objectives described above and contribute to the achievement of the European Green Deal targets.

In particular, the greening[3] systems, which have not produced the sought after effects in terms of environment and climate (EU, 2017), have been replaced by a proposed "reinforced" cross-compliance[4] (Atorino, 2018) and by the introduction of eco-schemes, which will provide stronger incentives for climate and environment friendly farming practices.

With the new CAP, all payments will therefore be subject to stricter environmental and climatic requirements, according to the "reinforced" cross-compliance, which based on the system implemented until 2020, increases the number of rules to be respected. In particular, for the climate and the environment, there are 13 practices based on EU minimum standards, which have as main issue climate change, water, soil, biodiversity

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[3]The greening is an environmental action introduced in the 2014-2020 programming cycle under which the farmers receive the green direct payment if they comply with three mandatory practices that benefit the environment (soil and biodiversity in particular).

- Crop diversification: a greater variety of crops makes soil and ecosystems more resilient. Farms with more than 10 ha of arable land have to grow at least two crops, while at least three crops are required on farms with more than 30 ha. The main crop may not cover more than 75% of the land. There are exemptions to the rules, depending on the individual situation.
- Maintaining permanent grassland: grassland supports carbon sequestration and protects biodiversity (habitats). The ratio of permanent grassland to agricultural land is set by EU countries at national or regional level (with a 5% margin of flexibility). Moreover, EU countries designate areas of environmentally sensitive permanent grassland. Farmers cannot plough or convert permanent grassland in these areas.
- Dedicate 5% of arable land (farmers with exceeding 15 ha) to areas beneficial for biodiversity: ecological focus areas (EFA), for example trees, hedges or land left fallow that improves biodiversity and habitats.

[4] In order to receive EU income support through direct payments, farmers must respect a set of basic rules. The interplay between this respect for rules and the support provided to farmers is precisely called cross-compliance.
Rules farmers are expected to comply with include the Statutory Management Requirements (SMR) and Good Agricultural and Environmental Conditions (GAEC).
The SMR include EU rules on public, animal and plant health animal welfare and the environment.
The GAEC concern the standards to prevent soil erosion by defining minimum soil cover and minimum land management practices; maintain soil organic matter and soil structure; maintain permanent grassland; protect biodiversity and ensure the retention of landscape features through, for example, a ban on cutting hedges and trees during the bird breeding and rearing season; protect and manage water through the establishment of buffer strips along water courses, authorisation on water for irrigation and protection of ground water from pollution.

and landscape (10 Good Environmental Agronomic Conditions and 4 Statutory Management Requirements[5]). Greening standards are also included, such as crop rotation, maintenance of permanent grassland, prohibition of conversion or ploughing ofpermanent grassland in Natura 2000 sites.

The ecological schemes, the new tool under the first pillar, are designed to support and incentivize farmers who engage in practices that benefit the climate and the environment, which go beyond the cross compliance. The acceptance of ecological schemes by farmers is elective, while Member States are required to develop such schemes within their National Strategic Plans, allocating at least 25% of their budget to them.

Member States may decide to include agricultural practices such as organic farming, agro-ecology (i.e. crop rotation with leguminous crops) or a low-intensity grass-based farming system and, in addition carbon farming, for example with conservation agriculture or the extensive use of permanent grassland crops. Other agricultural practices that could be supported by eco-schemes include precision farming to reduce inputs or the use of feed additives to reduce emissions from enteric fermentation, and husbandry practices for animal welfare and/or reducing the needs for antimicrobial substances[6].

Also in the "second pillar" of the CAP - support for rural development - there is a wide range of tools for the benefit of the environment and the climate, some of which will continue to take the form of per hectare payments to farms. An important category is payments for environmental, climate and other management commitments – which include what are currently known as "agri-environment-climate commitments" (and conversion to, or maintenance of, organic farming) and compensate farmers and other land managers for having voluntarily engaged for several years in beneficial practices for the environment and climate defined by the Member State.

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[5] CG01: Direttiva 2000/60/CE del Parlamento europeo e del Consiglio, del 23 ottobre 2000, che istituisce un quadro per l'azione comunitaria in materia di acque: articolo 11, paragrafo 3, lettera e) e articolo 11, paragrafo 3, lettera h), per quanto riguarda i requisiti obbligatori per controllare le fonti diffuse di inquinamento da fosfati.
CG11: Regolamento (UE) 2016/429 del 9 marzo 2016, relativo alle malattie animali trasmissibili, limitatamente all'afta epizootica, alla malattia vescicolare dei suini e alla febbre catarrale ("blue tongue").
CG13: Direttiva 2009/128/CE del Parlamento europeo e del Consiglio, del 21 ottobre 2009, che istituisce un quadro per l'azione comunitaria ai fini dell'utilizzo sostenibile dei pesticide.

[6] List of potential agricultural practices that eco-schemes could support published by the European Commission - https://ec.europa.eu/info/news/commissionpublishes-list-potential-eco-schemes-2021-jan-14_en#moreinfo

Similar financial mechanisms are foreseen to support environment and climate protection and to help maintaining agriculture in areas of particular difficulty due to natural constraints such as in mountain areas) including funding for knowledge development (e.g. farm specific advice on limiting greenhouse gas emissions); investments (e.g. in more water and energy efficient equipment); innovation (e.g. projects to adapt precision farming techniques to areas where they are not currently applied); and cooperation (e.g. for farms for the joint supply of waste for sustainable energy production).

Member States will be obliged to allocate at least 30% of EU funding foreseen for the second pillar The flexibility of choices and implementation models at national level is undoubtedly an advantage which, if exploited in a virtuous way, can increase the environmental effectiveness of the first pillar.

At the same time, the eco-regime also presents some critical issues, including the possibility that Member States do not finance this instrument with an adequate share of direct payments; if, on the other hand, it is adequately financed, it is necessary to avoid that it does not become a substitute (or competitor) of the voluntary measures of the second pillar. The choices made by each Member State will be therefore strategic for the development of truly effective actions in achieving the objectives set by the Commission (D'Andrea, 2019).

The proposed new CAP has been the subject of extensive negotiations between the European Parliament, the Council of the EU and the European Commission and was formally adopted on 2 December 2021 with implementation scheduled for 1 January 2023.

References Chapter I

Agovino, M. C. (2019). Agriculture, climate change and sustainability: The case of EU-28. *Ecological Indicators*, 105: 525-543.

Adewale, C., Reganold, J. P., Higgins, S., Evans, R. D., Carpenter-Boggs, L. (2018). Improving carbon footprinting of agricultural systems: Boundaries, tiers, and organic farming. Environmental Impact Assessment Review, 71: 41-48.

Aguilera, E., Diaz-Gaona, C., Garcia-Laureano, R., Reyes-Palomo, C., Guzmán, G. I., Ortolani, L., Rodriguez-Estevez, V. (2020). Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review. *Agricultural Systems*, 181, 102809

Albrecht, T., Crootof, A., Scott, C. (2018). TheWater-Energy-Food Nexus: A systematic review of methods for nexus assessment. *Environ. Res. Lett. 2018, 13*.

Arora, N. K. (2019). Impact of climate change on agriculture production and its sustainable solutions. Environmental Sustainability, 2(2): 95-96.

Atorino L., Ciccarelli F., Ronga M. (2018). Clima e ambiente nella Pac post 2020. *Agriregionieuropa*-Associazione Alessandro Bartola, Ancona.

Bajaj, P., Thakur, S. (2022). Carbon Dioxide Capture and Sequestration to Achieve Paris Climate Targets. In Climate Change (pp. 215-233). Springer, Cham.

Brevik, E. C., Slaughter, L., Singh, B. R., Steffan, J. J., Collier, D., Barnhart, P., Pereira, P. (2020). Soil and human health: current status and future needs. Air, Soil and Water Research, 13, 1178622120934441.

Cortignani, R., Dono, G. (2019). CAP's environmental policy and land use in arable farms: An impacts assessment of greening practices changes in Italy. *Science of the Total Environment*, 647: 516-524.

Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J. P., Iglesias, A., Xoplaki, E. (2018). Climate change and interconnected risks to sustainable development in the Mediterranean. Nature Climate Change, 8(11): 972-980.

Dinam, D. (2019). Debating Europe’s future. *Irish Political Studies*, 490-506.

EEA. (2019). *Climate change adaptation in the agriculture sector in Europe.* Report No 4/2019. Available online: https://www.eea.europa.eu/publications/cc-adaptation-agriculture.

EU. (2018). *REGULATION (EU) 2018/842 of the European Parliament and of the Council on binding annual greenhouse gas emission reductions by Member States from 2021 to 2030 contributing to climate action to meet commitments under the Paris Agreement.*

EU. (2021). Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 (‘European Climate Law’).

EU. (2021). Regulation (EU) 2021/1119 of the European Parliament and of the Council of 30 June 2021 establishing the framework for achieving climate neutrality and amending Regulations (EC) No 401/2009 and (EU) 2018/1999 (‘European Climate Law’).

EU-COM. (2019). *The European Green Deal, COM (2019) 640 Final.*

Eurostat. (2021, September). *Agri-environmental indicator - soil erosion*. Tratto da https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_soil_erosion#Analysis_at_EU_and_country_level.

Hoff, H. (2011). Understanding the Nexus: Background Paper for the Bonn 2011 Conference: The Water, Energy and *Nexus.*Stockholm: Stockholm Environment Institute.

IPCC. (2021). *AR6 Climate Change 2021: The Physical Science Basis.*

IRENA and FAO (2021). Renewable energy for agri-food systems – Towards the Sustainable Development Goals and the Paris agreement. Abu Dhabi and Rome. *https://doi.org/10.4060/cb7433en*

Li, Y. L. (2020). Residue retention promotes soil carbon accumulation in minimum tillage systems: Implications for conservation agriculture. *Science of The Total Environment*, 740: 102809

Liu J, H. V.-W. (2018). Nexus approaches to global sustainable development. *Nature Sust, 1:* 466-476.

Loboguerrero, A. M. (2019). Food and earth systems: priorities for climate change adaptation and mitigation for agriculture and food systems. *Sustainability,* 11(5).

Malek, Ž. V. (2018). Adaptation of land management in the Mediterranean under scenarios of irrigation water use and availability. *Mitigation and adaptation strategies for global change*.

Meemken, E. M. (2018). Organic agriculture, food security, and the environment. *Annual Review of Resource Economics*, 39-63.

MISE, M. M. (2019). Piano Nazionale per l'Energia e il Clima.

Naidoo, D., Nhamo, L., Lottering, S., Mpandeli, S., Liphadzi, S., Modi, A. T., Mabhaudhi, T. (2021). Transitional Pathways towards Achieving a Circular Economy in the Water, Energy, and Food Sectors. *Sustainability*, 13(17), 9978.

Panagos, P. B. (2015). The new assessment of soil loss by water erosion in Europe. *Environmental science & policy,* 438-447.

Pe'Er, G., Zinngrebe, Y., Moreira, F., Sirami, C., Schindler, S., Müller, R., Lakner, S. (2019). A greener path for the EU Common Agricultural Policy. *Science*, 365(6452), 449-451.

Roesch-McNally, G. E. (2018). Barriers to implementing climate resilient agricultural strategies: The case of crop diversification in the US Corn Belt. *Global environmental change*, 206-215.

Rulli, M. C., Bellomi, D., Cazzoli, A., De Carolis, G., D'Odorico, P. (2016). The water-land-food nexus of first-generation biofuels. Scientific reports, 6(1): 1-10.

Skinner, C., Gattinger, A., Muller, A., Mäder, P., Flieβbach, A., Stolze, M., Niggli, U. (2014). Greenhouse gas fluxes from agricultural soils under organic and non-organic management—A global meta-analysis. *Science of the total environment*, 468: 553-563.

Sotte, F. (2021). La politica agricola europea. Storia e analisi. Collana Economia Applicata, Agriregionieuropa-Associazione Alessandro Bartola, Ancona.

Spinoni, J. N. (2017). Pan-European seasonal trends and recent changes of drought frequency and severity. *Global and Planetary Change,* 113-130.

Stephanie Roe, C. S.-J. (2019). Contribution of the land sector to a 1.5 °C world. *Nature Climate Change volume*.

Struik, P. C. (2017). Sustainable intensification in agriculture: the richer shade of green. A review. *Agronomy for sustainable development*, 1-15.

Tubiello, N. (2019). Greenhouse Gas Emissions Due to Agriculture. *Encyclopedia of Food Security and Sustainability*.

UN. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development.* Available online: https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E (accessed on 27 August 2021).

UN. (2018). *The Sustainable Development Goals Report 2018.* Available online: https://unstats.un.org/sdgs/files/report/2018/TheSustainableDevelopmentGoalsReport2018-EN.pdf (accessed on 20 July 2021).

United Nations (2019). Department of Economic and Social Affairs, Population Division Report. Available on: https://population.un.org/wpp/Publications/Files/WPP2019_PressRelease_EN.pdf.

Wada, Y. W. (2013). Multimodel projections and uncertainties of irrigation water demand under climate change. *Geophysical research letters*, 4626-4632.

Chapter II *Multi-sectoral approaches to resource management: a review of methods and tools*

2.1 The Water-Energy-Food nexus approach

In the last decades, there have been dynamic changes in phenomena and their consequences on different sectors that have required the transition from linear approaches to integrated approaches in both science and politics. Indeed, focusing on one-sector results in apparently optimal efficiency, which can have negative consequences in other sectors, aggravating and transferring problems to other sectors. Taking into account also, what was discussed in the previous chapter, it is necessary to adopt a holistic approach in the decision-making processes that at the same time allows us to comply with different and conflicting objectives aimed at guaranteeing socio-economic development, environmental protection and promoting human well-being (Zarei, 2020). In particular, the challenges of sustainable development require an approach that allows to improve efficiency in the use of resources and to address intersectoral issues in an integrated perspective (van Zanten, 2021).

This is even more necessary in light of the socio-economic, energy and environmental effects induced by the Covid-19 pandemic, which highlighted the need to adopt integrated and flexible approaches in policy definition to be able to adapt to the scarcity of resources, environmental constraints, and lifestyle changes (Nhamo, 2021).

Therefore, the identification of suitable integrated approaches to sustainability and their implementation to address economic and environmental challenges is of paramount importance in resource management (Naidoo, 2021).

In this context, as mentioned above, the Nexus approach has attained a central role both in the scientific and policy fields. The key element of the Nexus approach is its focus on the interactions between the different components of food, energy, water and climate, addressing them as an integrated and coherent system ruled by complex interrelationships. Therefore, an analysis of their connections can contribute significantly to the understanding and enhancement of the synergies between the various components of the systems, allowing the identification of solutions capable of contributing to the resilience of socio-economic and ecological systems (Dargin, 2019).

Nexus thinking concepts provide useful information for policy making and are therefore gaining in popularity. Initially applied mainly in developing countries (Dessoum, 2018; Mabhaudhi, 2019), they are currently finding widespread diffusion also in more advanced economies (Van den Heuvel, 2020; Papadopoulou, 2020; Kantor, 2017).

In applying the nexus approach to policy design and implementation, a crucial aspect is a clear description of the interconnections between the different components and their potential impacts on current and future socio-economic systems (Papadopoulou, 2020). There is no single method suitable for all situations, but the approach must get used to each specific situation (Albrecht, 2018).

Several tools allow applying the nexus approach to represent the synergies between systems variables from multiple points of view in relation to spatial scales, governance levels, interconnections and synergies between variables and the multiplicity of the actors involved.

A typical field of application is the analysis of the water-energy-food system, in which the nexus approach allows comprehensively representing the relationships between these three fundamental variables of sustainable development and to define systemic strategies.

However, Simpson (2019) points out that nexus approaches often fail to capture the same interactions between water, energy and food that they conceptually aim to address, and that it is necessary to move from "nexus thinking" to "nexus doing ", in line with the EU position on the need for a greater effort to develop operational approaches that help assisting in the identification and development of future nexus case studies (EU, 2018). It follows the need to constantly adapt the tools to guarantee both public and private stakeholders to compare valid alternatives in the assessment of the water - energy - food problem (Endo, 2020).

An in-depth analysis of the available literature (Stylianopoulou, 2020; Zhang, 2018; Yung, 2019; Khan, 2018; Kaddoura, 2017) highlighted the development of different methodologies and tools based on the nexus approach used to systemically represent the interconnections between the three fundamental resources, water, energy, food, trying to overcome the methodological gaps and the lack of quantitative data.

Among the examples that well represent the current state of knowledge, there are the water-energy-food models identified and used by the main world non-profit organizations, such as IRENA - International Agency for Renewable Energy (IRENA, 2015), UN - United Nations (UN, 2016) and FAO - Food and Agriculture Organization (FAO, 2014) the main ones of which are listed below.

The **Water Evaluation and Planning Model – WEAP** (WEAP, 2016) for conducting integrated water resource planning assessments. It allows estimating water demand, supply, runoff, infiltration, crop needs, flows, storage, pollution, treatment, discharge and water quality in different scenarios hydrological and political. The WEAP is also a scalable resource-planning tool, allows you to compare water supplies and demand, and is capable of forecasting demand. In addition to modeling water resources, this tool also extends to biomass, energy and climate.

The **Climate, Land, Energy and Water Strategies – CLEWS** (Welsch, 2014) an interdisciplinary tool that aims to quantify the use of resources, greenhouse gas emissions and the costs associated with achieving energy, water and food security objectives. The synergies and trade-offs within the different areas are represented using a toolkit consisting of the combination of several independent planning tools including WEAP-water model, LEAP-energy model and AEZ-land production tool.

The **Diagnostic Tools for Investments – DTI** (FAO, 2021) in water for agriculture and energy: Developed by FAO, it provides an estimate of ongoing planned investments in water resources for food and energy production projects. It facilitates the identification of concrete ways forward that reflect a country's institutional, legal and political realities and provides a solid foundation for policy and investment design and implementation.

The **Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism – MuSIASEM** (Giampietro, 2013): the approach is a resource accounting method that examines the metabolism patterns of socio-economic systems providing a characterization at differentlevels and scales of socio-economic activities and ecological constraints. It was applied to analyze the link in relation to heterogeneous factors such as population dynamics, greenhouse gas emissions and changes in land use both on a national and sub-national scale. It can be used as a diagnostic or a simulation tool. In the first case, it can provide a snapshot of of the current metabolic process of society while, as a simulation tool, it can provide an analysis of possible scenarios from feasibility, viability and desirability perspectives.

The **WEF Nexus Tool 2.0** (Daher, 2015)**:** an input-output model for the analysis of national resource needs associated with different food self-sufficiency scenarios. Users identify data inputsthat provide a contextual and localized basis to the model: local food profile, national water and energy portfolios, agricultural conditions, and food import-export portfolio.

Consequently, the tool specifies the total needs for water, land and energy, the carbon footprint, financial costs and sustainability of the user-defined food efficiency scenario. It is a web-based online tool and consequently is accessible to a wide range of users (e.g. researchers, policy makers from both developed and developing countries). Furthermore, its operation is quite simple, not requiring the insertion of a large amount of data with a high degree of detail.

In different ways, all of these tools express the principle of the Water-Energy-Food Nexus and aim to create a sustainable development path through an integrated decision-making process. Existing models not only investigate the technical implications, but also include external factors such as climate change and population growth. However, it is necessary to take a step forward to define new holistic frameworks towards the development of models that allow the definition of policies that maximize all the synergistic efficiencies between the components of the nexus (Mabrey, 2018).

One of the goals of thesis is to assess the impacts of climate change, agricultural and energy-environmental policies in terms of resource availability, productivity and land use. To this end an integrated methodological platform that models the agriculture system adopting a nexus approach must be developed and/expanded.
Thus, to understand the advantages and drawbacks of distinct modeling approaches and tools, a review of the main methods used in the analysis of the agriculturaland energy sector was carried out; the results are summarized in the next paragraphs.

2.2 Agricultural system modelling

In recent decades, there has been a growing increase in demands for agricultural systems science to address issues that transcend agriculture. From which changes to ensure greater profitability without harming the environment, to which systems are needed to adapt to the continuous changes that agriculture faces (including climate change, changes in the demand for agricultural products, volatility in energy prices and limitations in the availability of land, water and other natural resources) (Ahmed, 2022).

So, many methods have been used for optimal allocation of agricultural resources. These approaches have specific strengths, weaknesses and application complexities. Deterministic approaches allow for a direct link to field knowledge and physical processes but can be very complex and difficult to readily adapt to specific areas of study. Probabilistic approaches provide statistical models to explain uncertainties but are inherently unsuitable for predicting the impact of major disruptions due to reliance on historical data. Systems dynamics approaches allow modeling of complex systems and include feedback loops and delay responses but risk formulating incorrect policies by relying on invalidated model simulations. (Xie, 2018; Linker, 2020; Tang, 2020).

The several crop simulation models available have broad applications: in crop production systems, soil carbon, pest and disease losses, livestock production, food security, irrigation water, environmental performance, climate change adaptation and mitigation. Therefore, crop models create the deep knowledge of analyzed issues and can be used directly or as inputs of decision support tools (DST) to inform the decision makers in addressing policy questions (Jones, 2017a). Some applications are briefly reported below.

Two examples of applications for crop simulation to evaluate different management practices for different crops. The Decision Support System for Agro-technology Transfer (DSSAT) was a model used for irrigation management of wheat, maize barley, and sunflower crops under Mediterranean conditions (Malik, 2019). The CSM-CERES-Wheat and CSM-CERES-Maize models, however, to predict phenology and grain yield of durum wheat, common wheat, and maize in different Italian environments (Mereu, 2019).

Also, Azmat et al. (2021) have quantified the impacts of climate change on wheat phenology and yield in irrigated and arid regions of Pakistan by using APSIM and STICS crop models with CORDEX-SA regional climate models for future periods. The Agricultural Production Systems Simulator (APSIM) model was used to investigate how increasing temperature and CO_2 as well as changes in precipitation could affect potential yield of four annual crops (barley, forage maize, oats, and spring wheat) over five sites in Sweden (Morel, 2021).

Two FAO's agronomic models named AquaCrop and CROPWAT were applied to assess the impact of irrigation technology and strategy on the reduction of cotton water footprint in Northern Greece (Tsakmakis, 2018).

The European Common Agricultural Policy Regionalised Impact (CAPRI) Modelling System is an example of DST that was developed to support decision-making related to the Common Agricultural Policy (CAP). In particular, the CAPRI model is a model of partial economic equilibrium, which represents the agri-food sector of the European Union and the related policies, integrating numerous economic, environmental and social variables into the analysis at different geographical scales. Its use is therefore of particular interest when it comes to evaluating the effects of the Common Agricultural Policy and scenarios arising from its variation (Barreiro, 2021).

The major limitations shared by many of these models is the need of very specific data to develop precise and complex models, as well as, the upscaling or downscaling are complex processes that require coupling with multiple data sources.

The development of agricultural system models is in constant evolution through efforts of an increasing number of research organizations worldwide, an example is international program called Agricultural Model Inter-comparison and Improvement Project (AgMIP) that was started to make model comparisons and improvements by considering the interest and feedback of agricultural modelers across the globe that aim for more harmonized and open databases for agriculture (Jones, 2017b).

2.3 Energy system modelling

The main purpose of energy models is to provide information on how to optimally allocate energy resources, taking into account economic, natural, technical and political constraints (Herbst, 2012). Therefore, examining the energy sector in isolation can generate misleading results, especially given the synergies and trade-offs between energy and natural flows. The more a model is able to grasp these relationships (for example, the impact of energy use on climate change, the impact of food production on energy demand, etc.) the greater its reliability and utility of outputs produced by it in terms of decision support in the development of sustainable policies.

Energy models must therefore take into account the aspects of the Nexus in order to minimize natural (related to the potential scarcity of resources, water and land in particular), social and economic risks (Del Granado, 2018).

In literature there are several energy systems modeling tools that have been or could potentially be used in addressing the Nexus approach (Semertzidis, 2015), below a brief description of the selection of these.

Computable General Equilibrium (CGE): Used for long-term simulations, CGE models analyze the economic implications of policies (e.g., CO_2 tax), assuming that all markets are in equilibrium. Generally, CGE models do not consider the technological details that might be important in assessing the effects of policies. GEM-E3 (Skelton, 2020) is an example of these models that covers the interactions between the economy, the energy system and the environment. It is especially designed to evaluate energy, climate and environmental policies. GEM-E3 canevaluate consistently the distributional and macro-economic effects of policies for the various economic sectors and agents across the countries, it contributed to the EU's 2030Climate and Energy Framework (Nèmeth, 2015). Another example is the GTAP modelsinternational trade flows, based on input-output structure of each country, which links industries together. It assumes perfectly competitive markets and that a change in any partof system will affect the entire world. The version GTAP-E addresses environmental and energy problems and has a module for CO_2 emissions resulting from the use of commodities in the production process (Saini, 2012).

Econometrics models: Oriented to test economic theory through empirical evidence, they currently include open and growth-based macro econometric models, with trend/analysis of time series data on a higher level of aggregation. Their main limitation lies in the strong dependence on data in order to generate reliable results. An example of application is E3ME (Mercure, 2018), an economic-energy systems-environment modelling tool used for policy assessment. The most common use is evaluating the impacts of an input shock through ascenario-based analysis. The shock could be a policy change, an economic change assumption or another model variable. It interrogates historical data to try to determine behavioral factors on an empirical basis and does not assume optimal behavior. Like other economic modelling tools, E3ME provides limited social factors coverage compared to the economic factors and environmental impacts (Mercure, 2016).

Input-output models: Suitable for short-term assessment of policies, as they can only provide a static image of the economic structure based on historical data illustrating sectoral production techniques describing the total flow of goods and services of an economic system in terms of production, added value and specific technical input / output coefficients. Garrett-Peltier (2017) uses Input-Output (I-O) approach to evaluate public and private spending in clean energy and compare it to the effects of spending on fossil fuels.

Partial Equilibrium / Optimization: Used to support the decision-making process by providing policy makers with detailed information on technologies and resources on both the demand and supply sides. Partial equilibrium models are characterised by a high technology detail both in the supply and demand side and define the optimal set of technological choices to achieve multiple objectives at the minimum feasible cost in relation to predefined exogenous constraints. The focus is on the energy sector, representing with technological detail the supply and demand side. Interrelationships and effects on the general economy are not considered. There are several examples of applications of these models to assess climate and energy policies for EU Commission, as well as for national and local authorities. The most utilised are PRIMES (Price-induced market equilibrium system) (Capros, 2008) developed by the E3MLab at National Technical University of Athens (NTUA) and used for the long term and the study of structural change in energy markets, POLES (Prospective Outlook on Long-term Energy Systems) (Criqui, 2015) a world energy-economy partial equilibrium simulation model of the energy sector that covers entire energy balance across countries and regions and the TIMES (The Integrated MARKAL-EFOM System) (Loulou, 2016) a partial equilibrium model generator developed as part of the IEA-ETSAP's methodology for energy scenario analysis that will be described in more details in the following chapter.

The technical features and literature review allowed us to select the IEA-ETSAP TIMES as the best suited to set up a comprehensive modeling framework for the agricultural sectoe. The main reasons that oriented the choice towards the IEA-ETSAP TIMES are based on the fact that it combines two different but complementary systematic approaches to energy modeling: a technical-engineering approach and an economic approach, capable of capturing both energy complexity and technology advancements. Energy system and single-sector analyses can be performed while long term sustainability goals are evaluated through scenario analysis. Moreover a wide dataset of technologies can be evaluated and compared and uncertainties can be taken into account.

Some examples of application of the IEA TIMES and Nexus approach to the agricultural sector can be found in literature (e.g. Chiodi, 2015; Sehn, 2020). These papers represented a valid starting point for developing an innovative model that represent the agricultural system of the Basilicata Region based on the WEF nexus approach focusing on land use as a guiding variable and including non-energy resources (water, fertilizers, pesticides). Using TIMES for WEF modeling also takes advantage from the existing local scale TIMES Basilicata energymodel (Di Leo, 2015), which may be connect to the agricultural model in a future developmentto allow analysisng in a global perspective synergies and competition between the sectors in a circular economy perspective.

References Chapter II

Albrecht, Tamee R., Arica Crootof, and Christopher A. Scott. (2018) The Water-Energy-Food Nexus: A systematic review of methods for nexus assessment. *Environmental Research Letters*13.4 : 043002.

Ahmed, Z., Gui, D., Qi, Z. et al. (2022) Agricultural system modeling: current achievements,innovations, and future roadmap. *Arab J Geosci* 15: 363 . https://doi.org/10.1007/s12517-022-09654-7.

Azmat, M., Ilyas, F., Sarwar, A., Huggel, C., Vaghefi, S.A., Hui, T., Qamar, M.U., Bilal, M., Ahmed, Z. (2021) Impacts of climate change on wheat phenology and yield in Indus Basin,Pakistan. *Sci Total Environ* 790:148221. https://doi.org/10.1016/j.scitotenv.2021.14822.

Barreiro Hurle, J., Bogonos, M., Himics, M., Hristov, J., Perez Dominguez, I., Sahoo, A.,I ... & Elleby, C. (2021). Modelling environmental and climate ambition in the agricultural sector with the CAPRI model (No. JRC121368). Joint Research Centre (Seville site).

B.T. Daher, R.H. Mohtar (2015) Water-energy-food (WEF) Nexus Tool 2.0: guiding integrativeresource planning and decision-making. *Water Int*., 10.1080/02508060.2015.1074184

Dargin, J., Daher, B., & Mohtar, R. H. (2019). Complexity versus simplicity in water energy food nexus (WEF) assessment tools. *Science of the Total Environment*, 650: 1566-1575.

Del Granado, P. C., Van Nieuwkoop, R. H., Kardakos, E. G., & Schaffner, C. (2018). Modelling the energy transition: A nexus of energy system and economic models. *Energy strategy reviews*, 20: 229-235.

Dessoum, B. (2018) L'approccio Nexus (acqua – energia – cibo) nella valutazione dei progetti di cooperazione internazionale allo sviluppo rurale. Energia, ambiente e innovazione,3:110-115. DOI 10.12910/EAI2018-068.

Di Leo, S., Pietrapertosa, F., Loperte, S., Salvia, M., Cosmi, C. (2015) Energy systems modelling tosupport key strategic decisions in energy and climate change at regional scale. *Renewable and Sustainable Energy Reviews*, 42: 394-414. DOI 10.1016/j.rser.2014.10.031.

Endo, A., Yamada, M., Miyashita, Y., Sugimoto, R., Ishii, A., Nishijima, J., ... & Qi, J. (2020). Dynamics of water–energy–food nexus methodology, methods, and tools. *CurrentOpinion in Environmental Science & Health*, 13: 46-60.

EU (2018) Position Paper on Water, Energy, Food and Ecosystems (WEFE) Nexus and SustainableDevelopment Goals (SDGs) Journal.

FAO (2014). Walking the nexus talk: in the context of sustainable energy for all initiativehttp://www.fao.org/3/a-i3959e.pdf .

FAO (2021). Diagnostic Tools for Investments in Water for Agriculture and Energy (Food and Agriculture Organization of the United Nations (FAO)) available at: www.fao.org/land-water/databases-and-software/diagnostic-tools-for-investment/en.

Garrett-Peltier, H. (2017). Green versus brown: Comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model. *Economic*

Modelling, 61: 439-447.

Giampietro M., (2013) An Innovative Accounting Framework for the Food-energy-water Nexus: Application of the MuSIASEM Approach to Three Case Studies. Food and AgricultureOrganization of the United Nations.

Herbst, A., Toro, F., Reitze, F., & Jochem, E. (2012). Introduction to energy systems modelling. *Swiss journal of economics and statistics,* 148(2): 111-135.

IRENA (2015) Renewable energy in the water, energy, & food nexus http://www.irena.org/documentdownloads/publications/irena_water_energy_food_nexus_2015.pdf.

Jones (a), J. W., Antle, J. M., Basso, B., Boote, K. J., Conant, R. T., Foster, I., ... & Wheeler, T. R. (2017). Brief history of agricultural systems modeling. Agricultural systems, 155:240-254.

Jones (b), J. W., Antle, J. M., Basso, B., Boote, K. J., Conant, R. T., Foster, I., ... & Wheeler, T. R. (2017). Toward a new generation of agricultural system data, models, and knowledge products: State of agricultural systems science. *Agricultural systems,* 155: 269-288.

Kantor, C., McLean, E., Kantor, M. (2017) Climate Change Influence on Agriculture and the Water-Energy-Food Nexus in Central and Eastern European Countries. Notulae Scientia Biologicae, 9(4): 449-459. DOI 10.15835/nsb9410193.

Kaddoura, S. El Khatib (2017) Review of water-energy-food Nexus tools to improve the Nexus modelling approach for integrated policy making. *Environ. Sci. Pol.*, 77:, 114-121, 10.1016/j.envsci.2017.07.007

Khan, P. Linares, M. Rutten, S. Parkinson, N. Johnson, J. Garcia-Gonzalez (2018) Spatial and temporalsynchronization of water and energy systems: towards a single integrated optimization model for long-term resource planning. *Appl Energy*, 210: 499-

Linker, R. (2020) Unified framework for model-based optimal allocation of crop areas and water. *Agric. Water Manag*., 228:, 105859

Mabhaudhi, T., Nhamo, L., Mpandeli, S., Nhemachena, C., Senzanje, A., Sobratee, N., Chivenge, P.P., Slotow, R., Naidoo, D., Liphadzi S., Modi, A.T. (2019) The Water–Energy–Food Nexus as a Tool to Transform Rural Livelihoods and Well-Being in Southern Africa. *Int. J. Environ. Res. Public Health*, 16 (16): 2970. DOI 10.3390/ijerph16162970.

Loulou R., Goldstein G., Kanudia A., Lettila A. (2016). Documentation for the TIMES Model. https://iea-etsap.org/docs/Documentation_for_the_TIMES_Model-Part-I_July-2016.pdf.

Mabrey, D., & Vittorio, M. (2018). Moving from theory to practice in the water–energy–food nexus: an evaluation of existing models and frameworks. *Water-Energy Nexus,* 1(1): 17-25.

Malik W, Dechmi F. (2019) DSSAT modelling for best irrigation management practices assessment under Mediterranean conditions. *Agric Water Manage* 216: 27–43.

Mercure, J. F., Pollitt, H., Bassi, A. M., Viñuales, J. E., Edwards, N. R. (2016). Modelling complex systems of heterogeneous agents to better design sustainability transitions policy. *Global environmental change,* 37: 102-115.

Mercure, J. F., Pollitt, H., Edwards, N. R., Holden, P. B., Chewpreecha, U., Salas, P., ... & Vinuales, J. E. (2018). Environmental impact assessment for climate change policy with the simulation-based integrated assessment model E3ME-FTT-GENIE. *Energy strategy reviews*, 20: 195-208.

Mereu, V., Gallo, A., & Spano, D. (2019). Optimizing Genetic Parameters of CSM-CERES Wheat and CSM-CERES Maize for Durum Wheat, Common Wheat, and Maize in Italy. *Agronomy*, 9(10): 665.

Morel, J., Kumar, U., Ahmed, M., Bergkvist, G., Lana, M., Halling, M., Parsons, D. (2021). Quantification of the Impact of Temperature, CO2, and Rainfall Changes on Swedish Annual Crops Production Using the APSIM Model. *Frontiers in Sustainable Food Systems*, 5: 178.

Naidoo, D., Nhamo, L., Lottering, S., Mpandeli, S., Liphadzi, S., Modi, A. T., ... & Mabhaudhi, T. (2021). Transitional Pathways towards Achieving a Circular Economy in the Water, Energy, and Food Sectors. *Sustainability*, 13(17): 9978.

Nhamo, L., Ndlela, B. (2021). Nexus planning as a pathway towards sustainable environmental and human health post Covid-19. *Environmental Research*, 192: 110376.

Papadopoulou, C. A., Papadopoulou, M. P., Laspidou, C., Munaretto, S., Brouwer, F. (2020). Towards a low-carbon economy: a nexus-oriented policy coherence analysis in Greece. *Sustainability*, 12(1): 373.

Simpson, G. B., Jewitt, G. P. (2019). The water-energy-food nexus in the anthropocene: moving from 'nexus thinking'to 'nexus action'. Current Opinion in Environmental *Sustainability*, 40: 117-123.

Skelton, A. C., Paroussos, L., Allwood, J. M. (2020). Comparing energy and material efficiency rebound effects: an exploration of scenarios in the GEM-E3 macroeconomic model. *Ecological Economics*, 173, 106544.

Stylianopoulou, K. G., Papapostolou, C. M., Kondili, E. M. (2020). Water–energy–food Nexus: a focused review on integrated methods. In Environmental Sciences Proceedings (Vol. 2, No. 1, p. 46). Multidisciplinary Digital Publishing Institute.

Tang, F. Zhang, B.A. Engel, X. Liu, Q. Yue, P. Guo (2020) Grid-scale agricultural land and water management: a remote-sensing-based multiobjective approach J. Clean. Prod., 265:, 121792.

Tsakmakis, I. D., Zoidou, M., Gikas, G. D., & Sylaios, G. K. (2018). Impact of irrigation technologies and strategies on cotton water footprint using AquaCrop and CROPWAT models. *Environmental Processes*, 5(1): 181-199.

United Nations Development Group Sustainable Development Goals Acceleration eration-toolkit/

Van den Heuvel, L., Blicharska, M., Masia, S., Sušnik, J., Teutschbein, C. (2020) Ecosystem servicesin the Swedish water-energy-food-land-climate nexus: Anthropogenic pressures and physical interactions. *Ecosystem Services*, 44: 101141. DOI 10.1016/j.ecoser.2020.101141.

van Zanten, J. A., Van Tulder, R. (2021). Towards nexus-based governance: defining interactions between economic activities and Sustainable Development Goals (SDGs). *International Journal of Sustainable Development & World Ecology*, 28(3): 210-226. doi.org/10.1080/13504509.2020.1768452

WEAP, (2016). Water Evaluation and Planning System. http://www.weap21.org/index.asp?action=200.

Welsch M., S. Hermann, M. Howells, H.H. Rogner, C. Young, I. Ramma, M. Bazilian, G. Fischer, T. Alfstad, D. Gielen, D. Le Blanc, A. Röhrl, P. Steduto, A. Müller, (2014). Addingvalue with CLEWS – Modelling the energy system and its interdependencies for Mauritius. *Applied Energy*, 113: 1434-1445,

Xie Y.L., D.X. Xia, L. Ji, G.H. Huang (2018) An inexact stochastic-fuzzy optimization model foragricultural water allocation and land resources utilization management under considering effective rainfall. *Ecol. Indic*. 92: 301-311

Yung L., Louder, E., Gallagher, L. A., Jones, K., Wyborn, C. (2019) How methods for navigating uncertainty connect science and policy at the water-energy-food nexus. *Front EnvironSci*, 7: , 37,

Zhang C., X.X. Chen, Y. Li, W. Ding, G.T. Fu (2018) Water-energy-food nexus: concepts, questionsand methodologies. *J Clean Prod*, 195: 625-639,

Zarei, M. (2020). The water-energy-food nexus: A holistic approach for resource security in Iran, Iraq, and Turkey. *Water-Energy Nexus*, 3: 81-94.

Chapter III *Methodology*

3.1 The ETSAP – TIMES modeling framework

The TIMES (The Integrated MARKAL-EFOM System), developed by the Energy Technology Systems Analysis Program (ETSAP) of the International Energy Agency (IEA), an autonomous intergovernmental organization born with the 1973-1974 oil crisis and based in Paris, France, is a partial equilibrium model generator, with a high technology detail, which uses linear-programming to compute a least-cost energy system, optimized according to several user exogenous constraints, over medium to long-term time horizons. It is widely used to represent local, national, and multiregional energy systems and to perform scenario analysis, exploring possible energy futures in relation to environmental and technical constraints, such as policy measures (IEA, 2016).

The main variable is energy demand of the end-use sectors (Industry, Residential, Commercial, Transport and Agriculture) that usually constitutes the “driving parameter” of the TIMES models.

The optimal least-cost solution is optimised provides the energy system configuration that corresponds to the best allocation of resources and technologies fulfilling the end-use demands and the exogenous limitations at the minimum total discounted cost of the whole system. The energy and environmental analyses are based on the comparison of the solutions obtained for contrasted scenarios, therefore the set up, calibration and optimization of a reference scenario is a prerequisite that provides the baseline for the further comparison in the scenario analysis.

The TIMES model structure is usually described through the Reference Energy and Materials System (REMS), which describes the entire supply–demand chain, providing an accurate representation of energy flows from supply/conversion technologies to demand processes. It allows representing all the components related to energy production and use, including emissions and materials. The supply chain describes the extraction, import/export and secondary production of primary resources (typically energy and materials) while the demand chain represents in detail the commodity flows through the network of real or fictitious technologies or processes, (e.g., mining, import, energy transformations, end-use devices). Any item produced or consumed by a technology or a process is called “commodity” (e.g., energy carriers, energy services, materials, money flows and emissions).

The key inputs to the TIMES model deal with all specific data that characterize the system under focus: energy demand, primary energy supply (availability of present and future sources), techno-economic factors (technology development and associated costs), environmental variables (e.g., GHG emission factors), and other policy parameters.

This research adopts the standard TIMES modeling framework as a starting point to develop a novel model focusing on the agri-food system through a WEF nexus perspective and that can be merged into the general energy modeling framework, exploiting all conversion processes and the end-use sectors related to agriculture.

3.2 The TIMES -WEF: a land-use driven model

3.2.1 Integrated Water-Energy-Food analysis: the TIMES Land-WEF model

The TIMES Land-WEF model represents an innovative application of the water-energy-food nexus approach embedded into the ETSAP-TIMES framework, where land use is chosen as the independent driving parameter to connect soil availability with input/output commodities. The choice of land use as driving parameter is motivated by the possibility of evaluating directly the effects of climate change and energy-environmental policies in terms of use of resources (energy, water, and land use), agricultural productivity, highlighting the synergies among the different sectors. The land use demand on the whole time horizon represents therefore the “end-use demand” to be fulfilled at the minimum feasible cost in compliance with all the exogenous constraints on resources. The overall objective is to ensure an optimal management of the territory to improve the use of endogenous resources, increase the resilience of the agri-food sector and facilitate the implementation of agricultural, energy and environmental policies.

The second independent driving parameter is represented by the number of Livestock heads to take into account energy consumption, water consumption and waste of livestock farming, and to assess the environmental impacts associated with the release of GHG emissions into the atmosphere.

The analytical structure reported in the flowchart of Figure 3.1 represents the agri-food system and its data input.

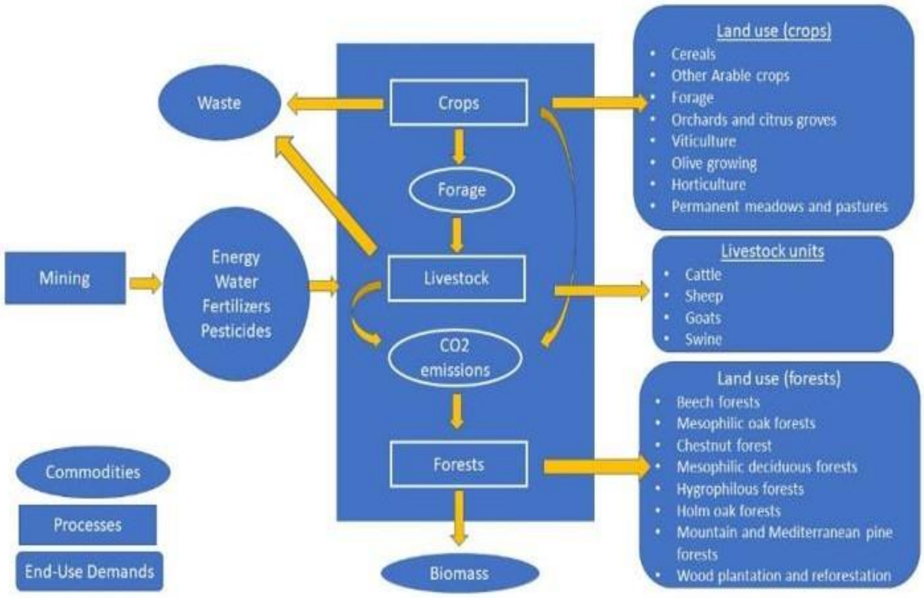

Fig 3.1 TIMES Land-WEF model flowchart

In this modelling approach, the used agricultural area expressed in hectares (UAA) and the forestry area (FA) are the output commodities representing the land use demands.

The used agricultural area categories include cultivation of cereals, other arable crops, forage, horticulture, viticulture, olive growing, orchards and citrus groves, permanent meadows and pastures. As regards vegetable production field horticulture and greenhouse horticulture are distinguished due to their different consumption. Also conventional and organic productions are modelled are different processes.

The forestry area is representative of the hectares of surface area covered by forests or the canopy of the forest or open wood. In the TIMES Land-WEF model, eight different types of forests are modelled (beech forests, mesophilic oak forests, chestnut forest, mesophilic deciduous forests, hygrophilous forests, holm oak forests, mountain and mediterranean pine forests, wood plantation and reforestation), whereas shrubs andMediterranean scrub areas have been excluded, as they are not subject to cutting.

Forests play a multifunctional role, contributing to the protection of biodiversity and the environment (through carbon sequestration) and to the economy (through the production of biomass as an energy resource). They are also particularly affected by climate change (droughts, forest fires, etc.), which reduces their carbon sequestration power and bioenergy resource potential.

As concerns livestock, the other important demand category, livestock heads units were considered as output commodities with reference to the species with significant energy consumption (cattle, sheep, goats, and swine).

This structure entails a potential integration of the TIMES-WEF agri-food model into the whole energy TIMES Basilicata model to make available a comprehensive modeling framework that analyses synergies and competition between the different demand sectors in a circular economy perspective.

The agricultural, forestry activities and livestock are thus modeled as end-use processes with associated input and output commodities, operating costs and other key parameters characterising these practices. New elements such as water, fertilizers, pesticides and CO_2 capture from forestry were included among the input commodities of a standard TIMES model (energy vectors and materials). Biomass residuals from all three categories, greenhouse gas emissions from both the combustion processes and agricultural activities are modelled as process outputs.

The links between livestock and agricultural activities are also modeled, such as the forage production deriving from agricultural crops for herbivorous species breeding.

3.2.2 The TIMES Land-WEF REMS: Characterisation of demand categories and processes

The structure of the TIMES Land WEF model is usually described through the Reference Energy and Material System (REMS). It represents the supply, the transformation and consumption of energy and materials by means of commodities and technologies. Commodities are energy carriers, materials (crops, biomass, and waste), monetary flows and emissions. Technologies (also called processes) are representations of physical devices that transform commodities into other commodities. The REMS is an oriented network diagram, in which processes are represented as boxes and commodities as vertical lines. The schematizing of parts of the considered system through the oriented diagrams is very useful in the model construction phase.

In Figure 3.2 the REMS of TIMES Land-WEF conventional and organic cereals production is represented starting from mining of diesel, fertilizers (Nitrogen N, Potassium P, Phosphorus K), active substances for conventional and organic cereals and water precipitation. These commodities are the input of two processes, which represent respectively the productionof conventional and organic cereals. In turn, the two processes have as output the conventional cereals produced and organic cereals produced respectively. Furthermore, they produce CO_2 emissions, biomass (denominated waste production) and other emissions. The conventional and organic cereals become the input of two dummy processes ("Conventional Cereals Land Use Process" and "Organic Cereals Land Use Process") modelled to consider crop yields. The two processes have as output the land use, expressed in hectares, of conventional cereals and organic cereals respectively. The CO_2 emissions is the input commodity of the process that models forestry, whereas biomass waste are in input for energy production.

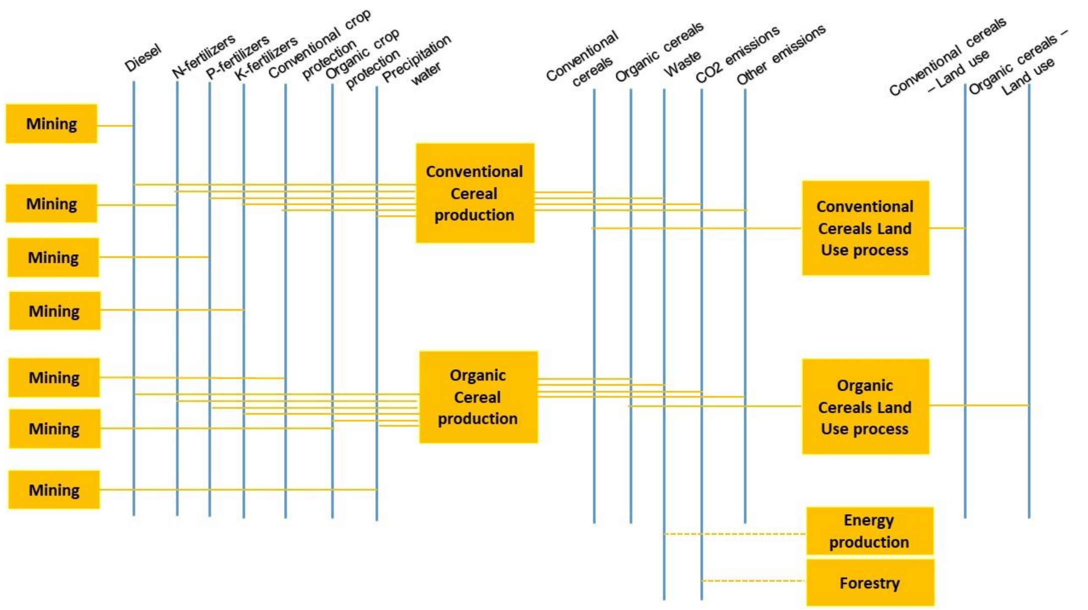

Figure 3.2 REMS of conventional and organic cereals.

The REMS of conventional and organic forage production (Figure 3.3) differs from the cereals REMS due to the absence of potash and phosphate fertilizers in the organic forage production process. In addition, the two commodities representing conventional forage and organic forage produced become the input of the process that models cattle livestock.

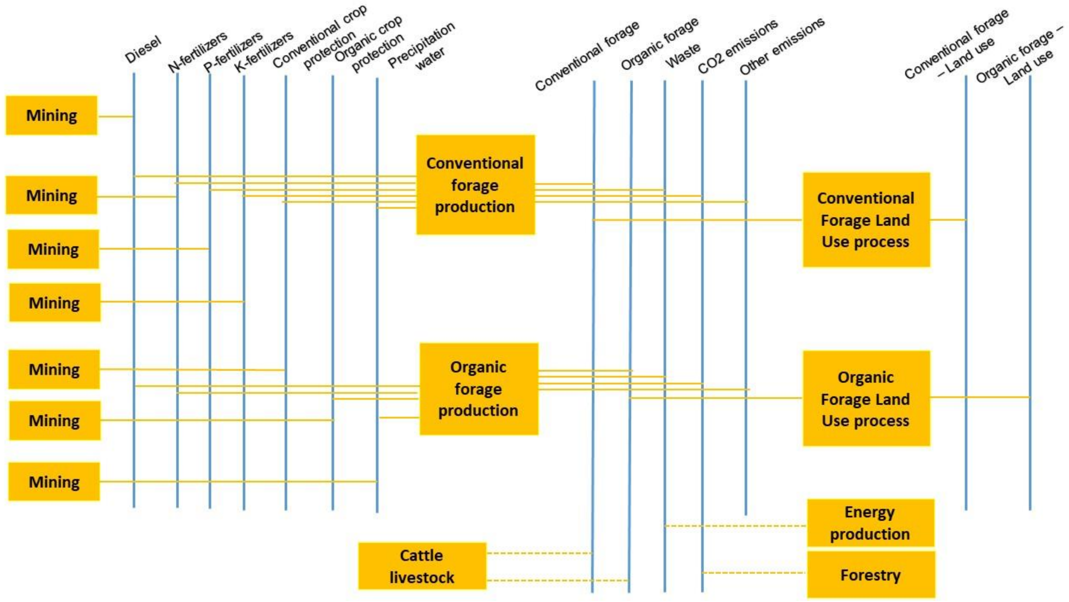

Figure 3.3 REMS of conventional and organic forage.

As regards the REMS of horticulture (Figure 3.4), three processes are considered to distinguish the productions in the field from those in the greenhouse. Moreover, electricity is an input commodity for greenhouse horticulture productions.

Irrigation water commodity is inserted to take account of its consumption in all three-production processes. Production waste is not present as output from production processes.

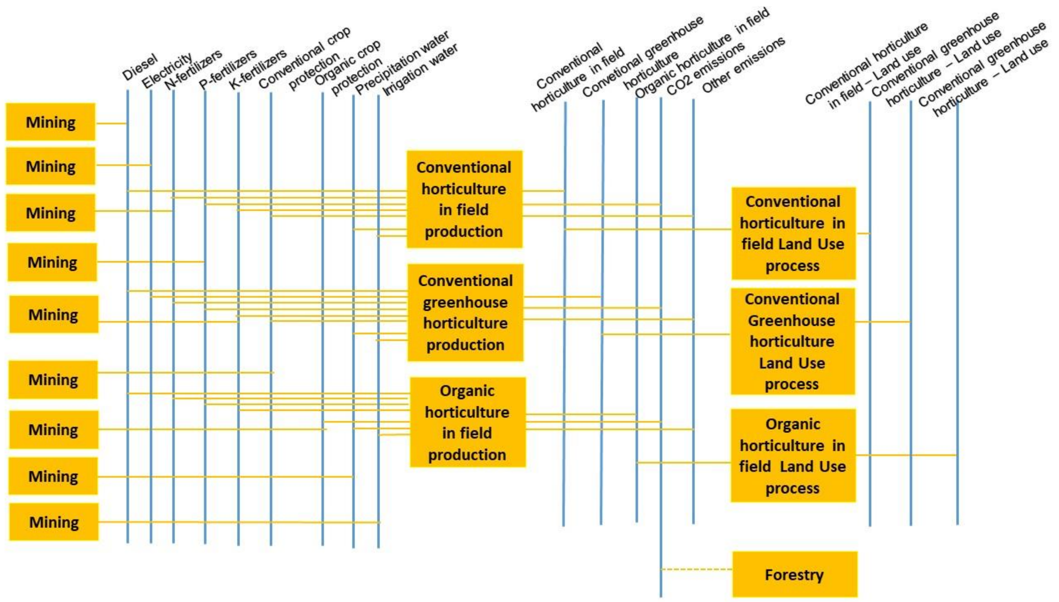

Figure 3.4 REMS of conventional and organic horticulture.

The structure of orchards and citrus groves REMS (Figure 3.5) is very similar to the horticulture REMS (Figure 3.4). In fact, also in this case irrigation water is considered in addition to precipitation water supply. All the three types of fertilizers are included as input commodities in both conventional and organic orchards and citrus groves processes.

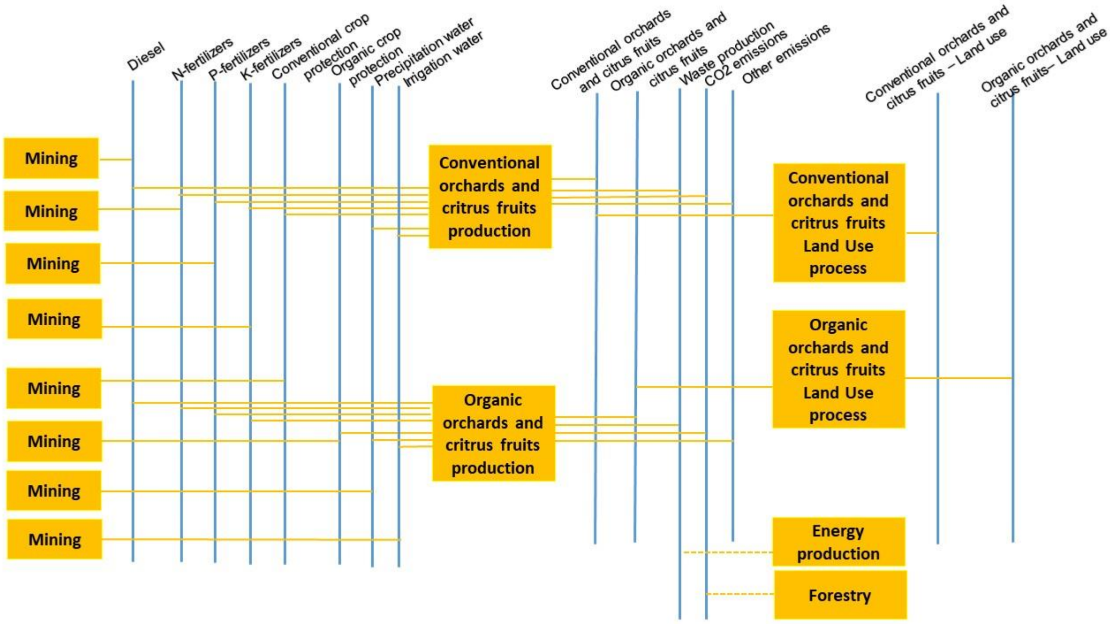

Figure 3.5 REMS of conventional and organic orchards and citrus groves.

The permanent meadows and pastures REMS (Figure 3.6) is simpler than other crop production REMS. In fact, conventional permanent meadows and pastures process has as input commodities diesel, nitrogen fertilizers, active substances for crop protection and precipitation water. Instead, in the organic production process nitrogen fertilizers and active substances for crop protection are not provided among input commodities. Moreover, conventional and organic crop production processes do not produce waste production as output commodity.

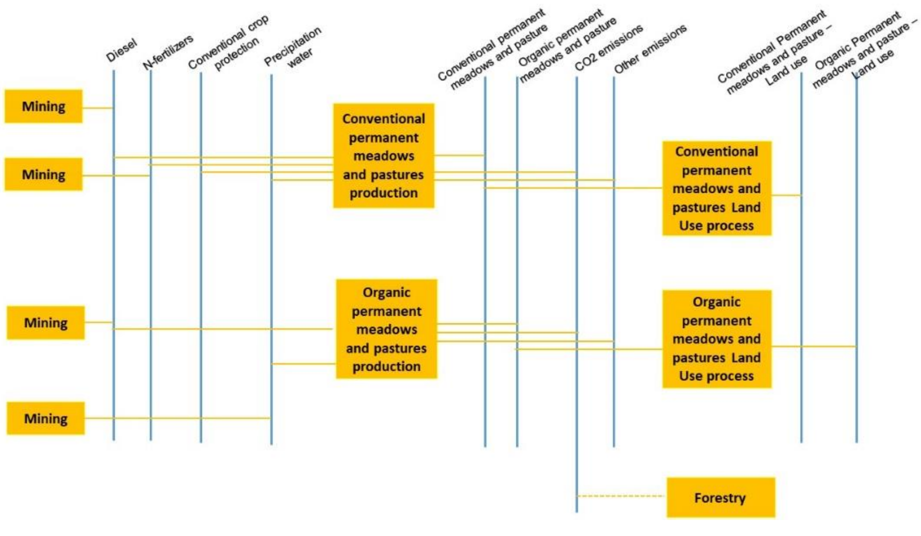

Figure 3.6 REMS of conventional and organic permanent meadows and pastures.

The oriented network diagram allows representing the livestock sector, highlighting the commodities in input and output and the related processes (Figure 3.7). For this sector each type of livestock is represented by a process characterized from energy commodities and water as input and from the number of animals, waste produced, emissions released as output commodities. Forage is an input commodity only for “Cattle livestock”. Produced waste is an input for biogas production and CO_2 emissions are an input for forestry.

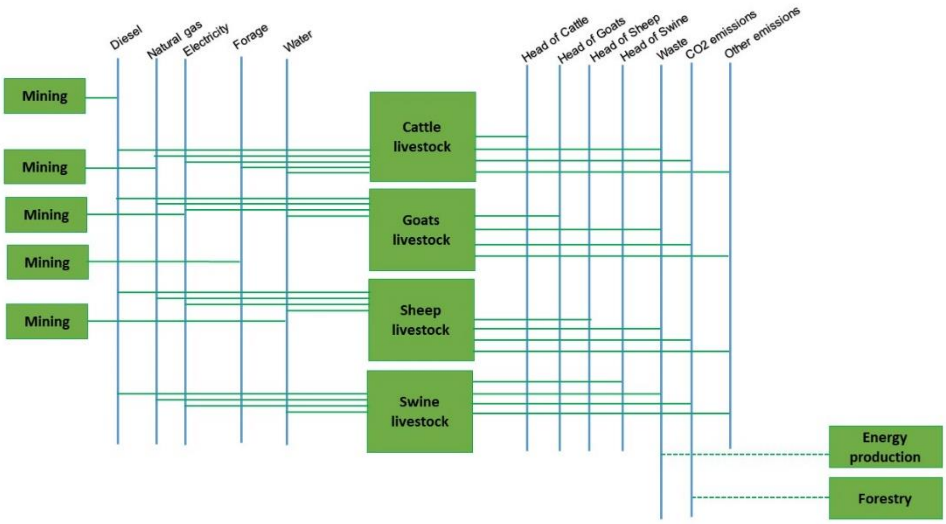

Figure 3.7 REMS of livestock sector.

The use of fictitious (dummy) technologies allows an appropriate transfer of commodities among. In Figure 3.8 the example of REMS related to Nitrogen fertilizers is reported. The Nitrogen fertilizers are an output commodity of the “mining” process, being an input commodity of a dummy technology that “transfer” them as output commodity to the agricultural processes according to the different cultivation processes.

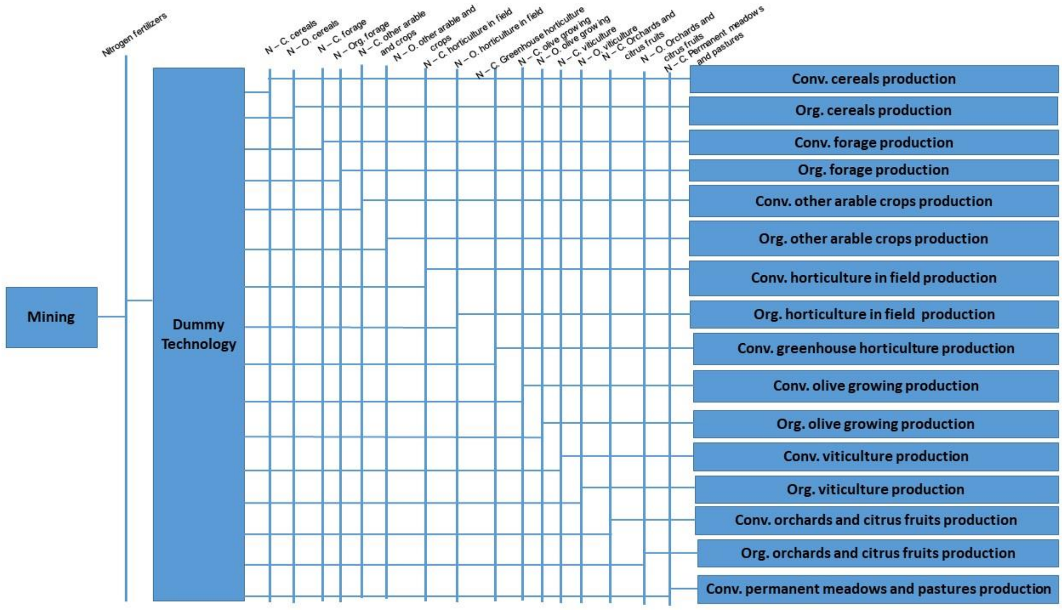

Figure 3.8 REMS of nitrogen fertilizers supply. Legend: N [Nitrogen fertilizers] C [Conventional] O [Organic]

The REMS of active substances for crop protection is characterized from two "mining" processes having as output the conventional and organic products respectively (Figure 3.9). Two dummy technologies have as output the conventional and organic commodities respectively, defined based on the crop production processes in which they are the input commodities. In this diagram the conventional and organic forage, the organic olive growing and the organic permanent meadows and pastures production processes are not represented.

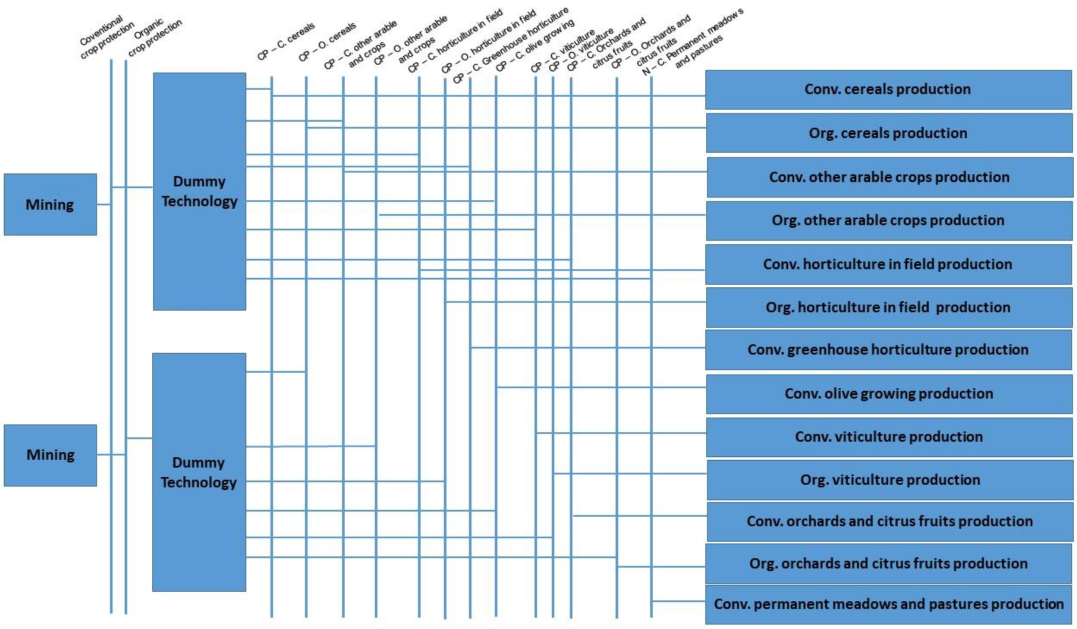

Figure 3.9 REMS of active substances for crop protection. Legend: CP [Crop Protection] C Conventional] O [Organic]

Regarding water supply for irrigation, diesel consumption has been considered (Figure 3.10) including therefore two mining processes for water and diesel supply respectively. Two dummy technologies have been defined accordingly with water irrigation being the output of the irrigation process becoming the input of the cultivation processes.

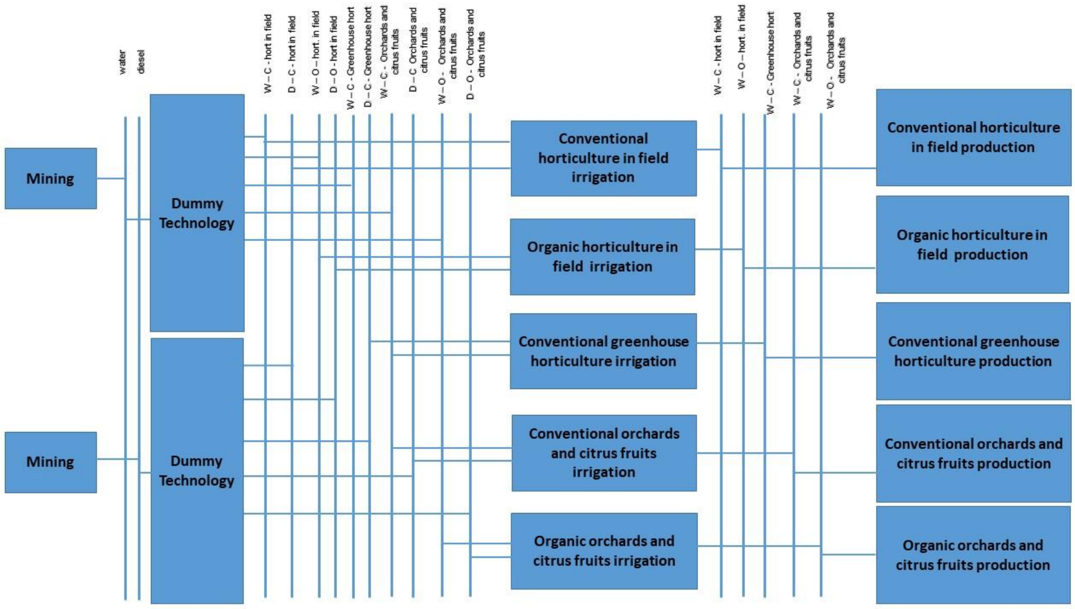

Figure 3.10 REMS of the irrigation system.

The REMS structure of forests is reported in Figure 3.11 with reference to the modeling ofbeech forests. Biomass and residual biomass are the output commodities from two different mining processes becoming the input commodities in the process modeling the beech forests. CO_2 emissions are determined from diesel consumption for crop productions, livestock, use of irrigation water and are absorbed by forests.

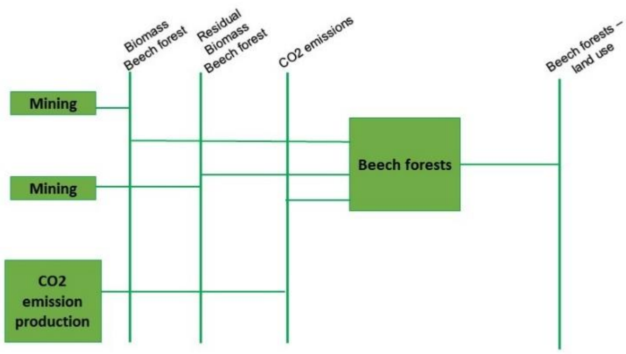

Figure 3.11 REMS of the beech forests

3.3 Data collection and analysis

The TIMES Land-WEF module input database is made up by a set of Excel spreadsheet, structured around two types of files:

- The Base Year Templates: they contain the basic data about input commodities (energy, water, fertilisers, pesticides), operating costs and output commodities (products and by-products – including straw, manure and emissions, and UtilizedAgricultural Area) in order to characterize the Forestry and Agricultural Activities in the base year. They provide the statistical data for the model calibration.
- The Scenario Files: a set of spreadsheets containing coherent demand projections, exogenous constraints on resources availability, and other parameters by scenario.

To test the applicability and consistency of the integrated approach developed through the TIMES Land-WEF modelling module, the TIMES model was customized according to the Basilicata region data as a pilot case.

3.3.1 The Basilicata Region case study

Basilicata is a relevant case study mainly due to the urgent threat that the effects of climate crisis represent for this territory. In fact, 55% of the Region is at risk of desertification (CNR, 2015), endangering the future of the agricultural sector, which plays a crucial role in the local economy. Therefore, for this Region mitigation policies and adaptation actions are a priority to increase the resilience of the territory and support agriculture, identifying sustainable pathways of production of local resources.

Basilicata is a region with a rural vocation, with a territory of 10’073 km^2 that is almost entirely mountainous (47%) or hilly (45%), including natural parks, landscapes and habitats of great value. The residents are about 553’254, with a density of 54.9 inhabitants per sq km and a negative demographic trend (Eurostat, 2020).

The flat area considered a rural area with specialized intensive agriculture is located on the Ionian side of Basilicata, represents 8% of the regional surface and is characterized by flat land and easy access to water resources. Its agriculture is of a specialized type with a high income, in fact, despite being a small area; it generates about 25% of the added value of the regional primary sector.

Within the hilly and mountainous areas, there are areas with more advanced agricultural models. Whose territory is mainly hilly with alternating plains. The agricultural activities practiced are arable and grazing, with the production of specialized crops in the flat areas. Moreover, the areas of the hinterland are mainly mountainous and characterized by large woods and pastures, by the scarce presence of specialized agriculture, largely due to the height and slope of the area, which is unfavorable to these crops (PSR, 2015).

The industrial sector is made up mainly by small and medium-sized enterprises, and counts among the large enterprises the automotive plant of the multinational Stellantis, formerly FCA group, located in Melfi (Banca d'Italia, 2021).

As for energy resources, Basilicata has the largest onshore oil and gas fields in Europe, with an annual production of 48'550'554'911 BBOE of oil and 1'493'816'334 smc of natural gas. These huge hydrocarbon deposits are located in the Basento Valley (natural gas) and Val d'Agri (oil), where the largest reservoir in continental Europe is located. The Lucanian resources, managed by Eni and Shell in Val d'Agri and Total, Mitsui and Shell in the Sauro Valley, account for more than 80% of the national production of hydrocarbons (MISE, 2021).

As regards renewable, Basilicata has strongly promoted the production of electricity from renewable sources, already exceeding in 2010 the objectives set by the Regional Environmental Energy Plan (PIEAR) for 2020, with a quantity of 981 MW from wind onshore (60% of the total renewable production), 359 MW from solar-photovoltaic (20%), 50 MW from biomass (15%) and 48 MW from hydroelectric (5%). The use of biomass to produce thermal energy was also supported by various policy measures. In 2017, 45% of the regional thermal and electrical energy needs were met by renewable sources, exceeding the target of 33% by 2020 set by national legislation (GSE, 2019).

Due to its wide geomorphological differences, mainly in altitude, the Region is characterized by a varied climate ranging from the continental one of the inland areas to the Mediterranean one of the coastal areas. There are six distinct pedoclimatic zones (Ionian, Bradanica, Northern Apennines, North Western Apennines and South Western

Apennines, Tyrrhenian) in which climate deeply influences the type of agriculture, particularly in inland and non-irrigated areas (Regione Basilicata, 2022).

The total agricultural area is 716’838 hectares accounting for about 70% of the regional surface. The forest area according to the Regional Forest Charter is about 355’409 hectares and is characterized by various species both from an environmental and vegetation point of view that make the regional territory a mosaic landscape.

As in most Mediterranean countries, large areas of Basilicata are particularly subject to soil degradation because of the pressure of contingent factors (climate changes, changes in land use, over-exploitation of resources, etc.). This highlights the importance of sustainable resource and forest management to improve land resilience and ensure the efficiency of a key sector for the local economy such as agriculture (Salvati, 2013; Coluzzi, 2019).

Despite its small contribution compared to other sectors, with an added value of 3% in 2019, the agricultural sector has a significant weight in terms of exports and employment, recording a positive trend for the latter which in recent years reaches a 7% increase in 2019, in contrast to other sectors. In particular, the high specialization achieved in the agri-food sector characterized by the production of a wide range of high-quality food products (most of which are included in the national list of DOP, IGP, DOC and DOCG brands of traditional agri-food products) could be a potential strength to increase the competitiveness of the whole regional system (Viccaro, 2018).

In this perspective, the 2014-2020 Rural Development Program has played a fundamental role by providing valuable financial support (680 M€) to encourage innovation in this sector in order to improve its economic performance and environmental sustainability (PSR, 2015).

3.3.2 The main data sources

The information necessary to implement the data input of the TIMES Land-WEF model for the characterisation of agricultural activities was collected and processed by consulting the main publicly available statistical databases as well as scientific reports with detailed content on the primary sector. The main sources consulted and the types of data extracted from each of them are described below.

- **National Institute of Statistics (Istat)[7]:** the Istat database, free available online, provided the data relating to the Utilised Agricultural Area (UAA), the annual agricultural productions, the number of animals brought up annually divided by species, the quantity of active substances contained in the pesticides, the volume of water used for irrigation purposes. The data for the year 2010 refer to the latest census available for Agriculture, while for the following years the values were estimated according to the criteria defined by Istat.
- **Farm Accountancy Data Network (FADN)[8]**: the annual sample survey set up at Community level[9] with a similar approach in all Member States was the reference source for microeconomic data on the economic-structural dynamics of agricultural holdings. The information system of the national FADN provided the data relating to the use of fertilizers, production costs for both agricultural and livestock activities
- **Regional Environmental Energy Plan (PIEAR)[10]:** the document explains the ten-year regional energy strategy of the Basilicata Region and provides the aggregate energy demand for the agricultural sector with the details of consumption for diesel, electricity and natural gas for the year 2010 (year of publication).
- **Regional Forest Map[11]:** main source of information for wooded areas. It provided information on the areas occupied by the various forest species, also taking into account the different forms of forest governance (high forests and coppice woods).
- **Chambers of Commerce:** the main source of information to calculate the average annual price of agricultural fertilizers and diesel, derived from the analysis of a detailed historical series of data (fortnightly price lists of petroleum products)

[7] Istat web site, agriculture sector database: http://dati.istat.it/Index.aspx?QueryId=37850
[8] Italian FADN web site, open source database: http://arearica.crea.gov.it/
[9] Regulation CEE 79/56 update by the Reg. CE 1217/2009
[10] The document is available online:
https://www.regione.basilicata.it/giunta/files/docs/DOCUMENT_FILE_543546.pdf
[11] The document is available online: http://basilicata.podis.it/atlanteforestale/

published by the Turin Chamber of Commerce (https://www.to.camcom.it/studi-e-statistica).

- **National Forestry Accounting Plan (NFAP)[12]:** National Forestry Accounting Plan (NFAP): the application of European legislation on the inclusion of forest management and other land uses in the greenhouse gas emission reduction targets set by the European Union for 2030[13] makes it mandatory for each Member State to draw up a NFAP to estimate the contribution of the forest sector to mitigate the effects of climate change. From the data provided by NFAP Italy, the average quantity of carbon sinks per forest species and the quantities of timber harvested annually were estimated.
- **Agroclimatic Observatory[14]:** free access portal of the Ministry of Agricultural, Food and Forestry Policies that reports detailed data with reference to the climatic variables that characterize the different areas of the country. It was used to estimate the average annual amount of rainfall on the territory of the Basilicata Region.
- **Annual reports of the Energy Service Manager[15]**: published annually, they provide a detailed analysis of the entire national energy system. Among the available data relating to electricity, those relating to the cost of MWh for the years 2010, 2015 were used.

- **Ministry of Ecological Transition[16]:** the average annual prices of LPG were deduced from the open data, Energy and Mining Analysis and Statistics.

- **Government Body for Waste and Water Resources of Basilicata (EGRIB)[17]:** tariffs for agricultural users were consulted to estimate the reference prices for irrigation and livestock water.

[12] The document is available online: https://www.mite.gov.it/sites/default/files/archivio/allegati/clima/NFAP_final.pdf

[13] Regulation (EU) 2018/841 of the European Parliament and of the Council of 30 May 2018 on the inclusion of greenhouse gas emissions and removals from land use, land use change and forestry in the 2030 climate and energy framework, and amending Regulation (EU) No 525/2013 and Decision No 529/2013/EU

[14] Basilicata open access website: https://www.politicheagricole.it/flex/FixedPages/Common/miepfy700_regioni.php/L/IT?name=00017

[15] The documents are available online: https://www.gse.it/dati-e-scenari

[16] The Ministry open access database: https://dgsaie.mise.gov.it/prezzi_carburanti_mensili.php

[17] The Egrib ', open access, water tariff data series https://www.egrib.it/tariffe/

3.3.3 The input database of the TIMES Basilicata Land- WEF

A detailed description of the process for the setup of the input data of the TIMES Land WEF model is reported in Figure 3.12 with reference to 2010 (the base year) and to the year 2015 (benchmark) in relation to the data of the Excel files and the data processing.

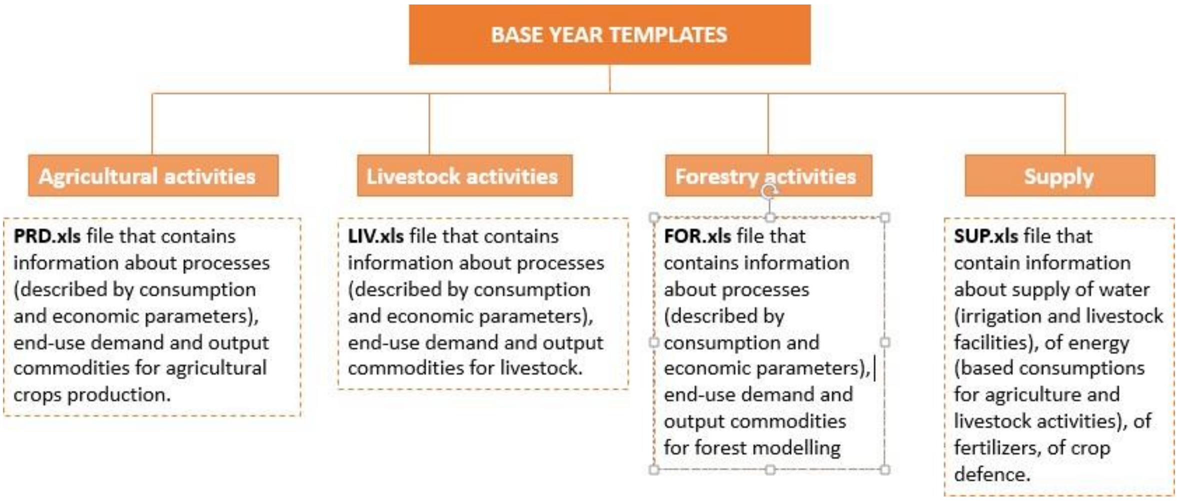

Figure 3.12 Scheme of information contended in the base year templates.

Agricultural activities

The choice of land use as end-use demand of the model is one of the innovative aspects introduced by TIMES Land-WEF model.

The estimate of the **Utilized Agricultural Area (UAA)** for the different types of crops analyzed was carried out considering the data of the Istat time series archive[18] (specifically, by consulting the agriculture section => crops and livestock => crops => area and production) which made it possible to evaluate the trend from 2010 to 2020 (Figure 3.13)

[18] The open access website: https://www.istat.it/en/archive/200906

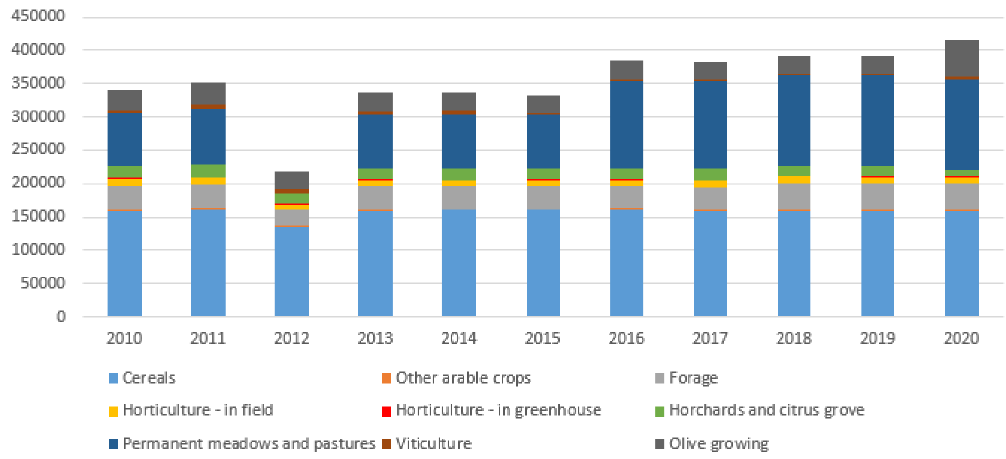

Figure 3.13 Hectares of UAA by crops in the period 2010-2020 (Basilicata Region).

In order to estimate the area dedicated to organic practices, it was necessary to integrate these data also with the information contained in the annual report on organic farming in Italy drawn up by the Ministry of Agricultural, Food and Forestry Policies[19]. The results obtained, shown in Table 3.1, provide a comprehensive overview of the distribution of hectares among the modelled crops present in Basilicata, distinguishing between conventional and organic cultivation practices. In addition, for horticulture, it highlighted the difference between greenhouse and open field production.

Table 3.1 Utilised Agricultural Areas - conventional and organic processes (Hectares).

UAA 2010	***Cereals***	***Forage***	***Other arable crops***	***Hort. - in the field***	***Hort.- in greenhouse***	***Viticulture***	***Olive growing***	***Orchards and citrus groves***	***Permanent meadows and pastures***	**Total**
Organic	19’425	6’423	543	2’025		727	2’864	2’978	9’509	**44’494**
Conventional	139’426	29’520	1’150	8’869	1’165	4’634	28’487	16’318	67’646	**297’214**
UAA 2015										
Organic	16’235	11’876	912	1’019		584	2’763	2’604	8’538	**44’530**
Conventional	144’240	26’397	1’692	8’223	1’038	2’175	23’973	14730	70’521	**292’991**

[19] Annual Reports “Bio in Cifre” are available on: https://www.sinab.it/reportannuali?field_tipologia_report_annuale=3758&search_api_fulltext=

Starting from the Istat database, the annual agricultural production was estimated for each of the crop processes identified by the model, differentiating between conventional and organic practices (Table 3.2).

Table 3.2 Agricultural production by crops (Tons).

Tons 2010	***Cereals***	***Forage***	***Other arable crops***	***Hort.- in the field***	***Hort.- in greenhouse***	***Viticulture***	***Olive growing***	***Orchards and citrus groves***	***Permanent meadows and pastures***	**Total**
Organic	91’037	45’999	891	58’549	0	7’025	5’559	66’201	6’278	**281’538**
Conventional	328’552	393’901	2’463	328.529	22’352	41’760	37’723	246’983	155’922	**1’558’185**
Tons 2015										
Organic	50’470	87’974	988	43’573	0	6’587	3’331	44’915	13’009	**250’846**
Conventional	414’789	306’426	2’876	264’982	21’216	32’185	36’235	235’066	156’791	**1’470’566**

The relationship between agricultural production and the used areas allowed calculating the yield per hectare for each category analysed (Table 3.3).

Table 3.3 Yield of main production crops (tons per hectares).

Yields 2010	***Cereals***	***Forage***	***Other arable crops***	***Horticulture -in the field***	***Horticulture- in greenhouse***	***Viticulture***	***Olive growing***	***Orchards and citrus groves***	***Permanent meadows and pastures***
Organic	4.69	7.16	1.64	28.91	0.00	9.66	1.94	22.23	0.66
Conventional	2.36	13.34	2.14	37.04	19.19	9.01	1.32	15.14	8.57
yields 2015									
Organic	3.11	4.25	1.08	42.76	0.00	11.29	1.21	17.25	3.22
Conventional	2.88	6.67	1.70	32.22	20.43	14.80	1.51	15.96	4.70

The estimate of residues from agricultural activities that can be reused for energy purposes was made taking into account the data reported in the literature (Statuto, 2019). In detail, for cereals and other arable land, on the basis of the area occupied by these crops, the total usable biomass was estimated considering the average values per hectare of straw produced (**2.61 ton/ha**) and an average humidity of **14%** (maximum permissible humidity to avoid the occurrence of chemical reactions of respiration, rot and growth of microorganisms).

The results obtained could in some way overestimate the availability of a resource that can be used for energy purposes, taking into account that a percentage could be left in the field as organic fertilizer or used in breeding (litter, feed, etc.).

Also for the vine, the olive tree and the orchards, the potential biomass for energy purposes was calculated on the basis of the occupied area and average values of pruning residues per hectare (respectively: **2.15 ton/ha**; **2.16 ton/ha**; **2.20 ton/ha**).

The results obtained considering the hectares of Agricultural Utilized Area for 2010 and 2015 are reported in Table 3.4.

Table 3.4 Potential dry matter by crops usable for energy scope (Tons).

Tons	**2010**	**2015**
Cereals		
Conventional	43’546	36’395
Organic	312’556	323’348
Other arable crops		
Conventional	1’401	2’353
Organic	2’967	4’365
Viticulture		
Conventional	1’563	1’255
Organic	9’963	4’676
Olive growing		
Conventional	6’186	5’968
Organic	61’531	51’781
Orchards and citrus groves		
Conventional	6’551	5’728
Organic	35’899	32’406

Also, the emissions of the main greenhouse gases (CO_2, CH_4 and N_2O) were estimated by considering the emission factors provided by the UNFCCC[20], distinguishing combustion emissions from process emissions. CO_2, CH_4 and N_2O emissions by combustion are due both to energy consumption for crop production and for irrigation (Table 3.5).

Table 3.5 Emission factors by combustion of main greenhouse gases (kton/PJ).

Unit (Kton/PJ)	**CO_2**	**CH_4**	**N_2O**
Diesel	69.3	0.012	0.014
Natural gas	56.1	0.003	0.003

As concerns emissions by process they are produced from livestock and they are expressed in ktons per head. CH_4 emissions are due to enteric fermentation and manure management, while for N_2O they are due to manure management (Table 3.6).

Table 3.6 Emission factors by process from livestock (kton/head).

Unit (Kton/head)	**Cattle**	**Sheep**	**Goats**	**Swine**
CH_4 - enteric fermentation	0.00007370	0.00000707	0.00000500	0.00000150
CH_4 - manure management	0.00001072	0.00000021	0.00000016	0.00000787
N_2O - manure management	0.00000053	0.00000001	0.00000009	0.00000009

Concerning N_2O emissions by process, they are also due to the use of nitrogen fertilisers (0.0000157 kton N_2O/ ton of fertiliser).

Furthermore, data on the economic performance of the companies surveyed by the FADN network were used to estimate the production costs of each eighth category (distinguishing by organic and conventional cultivation methods).

[20] Greenhouse Gas Inventory data. United Nations Climate Change. Available online: https://di.unfccc.int/time_series

In the elaboration of the microdata[21] provided by this census, as we will see later also for other variables, the first step was to classify the units (in this case n. 1445) according to the categories considered by the model, using the identification codes of the different plant species. The next step was to identify within the sample, through the code associated with each company, the companies that do not carry out any organic process and those that practice organic farming in whole or in part (Tab. 3.7).

Tab. 3.7 Plant species present in the FADN sample and aggregation in the categories analyzed in the TIMES Basilicata Land-WEF model.

Crop species (FADN)	**Crop categories TIMES Basilicata Land-WEF**
Oats, spelt, wheat, corn, barley, rye, and other grain cereals (organic, non organic).	Cereals
Chickpea, broad beans, lentils, and other grain legumes (organic, non organic).	Other arable crops
Watermelon, strawberry, eggplant, pepper, tomato, zucchini, escarole, and other vegetables (organic, non organic).	Horticulture
Alfalfa, grass of grasses, clover, legumes and other mixtures (organic, non organic).	Forage
Chestnut, apricot, peach, pear, orange, kiwi, mandarin and cherry (organic, non organic).	Orchard and citrus grove
Grape vine and table grape (organic, non organic).	Viticulture

Therefore, the variable costs per ton of main product obtained by each company were calculated, reduced by the expenditure components for energy (Fuels, Electricity and Heating), water, fertilizers (excluding the reuse of manure) and crop protection.

The data referred to the sample of companies were extended to the entire Basilicata Region (statistical universe target of the FADN sample) through a weighting procedure, on the basis of which each company registered in the FADN is assigned a sample base

[21] The microdata are not opensouce, they are provided on a justified request by CREA (Council for research in agriculture and the analysis of the agricultural economy) as we will see later also for other variables.

weight[22]. The obtained results relating to the costs per tons of crops typologies are reported in Table 3.8.

Table 3.8 Variable costs for crops (Euro/ton).

€/ton	***Cereals***	***Forage***	***Other arable crops***	***Viticulture***	***Olive growing***	***Orchards and citrus groves***	***Permanent meadows and pastures***
Organic	67.44	22.54	82.53	11.16	9.09	30.51	0.71
Conventional	65.57	18.26	65.14	9.17	11.94	38.24	7.99

Following the same calculation procedure, the results relating to horticulture were further elaborated, being extracted from the sample separately and analyzing the subcategories of cultivation process "in open field " and "in greenhouse". The results are reported in Table 3.9.

Table 3.9 Variable costs for horticulture (Euro/ton).

	€/ton
Horticulture	
in open field	
Conventional	93.04
Organic	13.84
in greenhouse	
Conventional	521.20

The analysis of the data relating to the FADN sample census for the year 2015 highlighted various anomalies, therefore only the data set relating to 2010 was taken into account.

Forestry activities

The hectares of **Forest Area (FA)** divided by species were estimated using the information of the Regional Forestry Charter, the most recent and detailed document available. In order to allow the calculation of residual biomass in the later stages of data processing, it was also necessary to take into account the different forms of forest

[22] Methodological note on the use of statistical weights in FADN survey is available on CREA website: https://rica.crea.gov.it/ponderazione-dei-risultati-27.php

governance (high forests and coppice woods). The total hectares considered exclude the residual quota destined to transitory stands. In addition, shrubs and Mediterranean scrub areas were excluded from the analysis, as they are not subject to cutting (Table 3.10).

Table 3.10 Hectares of forest area divided by species and form of forest governance.

	Form of forest governance		
Forest type	***High forest***	***Coppice forest***	**Total**
Beech forests	11’458	15’146	**26’604**
Mesophilic oak forests	53’645	108’719	**162’364**
Chestnut forests	24	8’462	**8’486**
Mesophilic deciduous forests	3’201	12’176	**15’377**
Hygrophilous forests	13’183	407	**13’589**
Holm oak forest	2’517	7’200	**9’717**
Mountain and Mediterranean pine forests	25’133	0	**25’133**
Wood plantation and reforestation	2’079	119	**2’198**
Total	111’240	152’228	**263’468**

The first step was to estimate the total annual biomass potential that could be harvested. Using the average values from literature (Cozzi, 2013); the growth for each forest type was then calculated, expressed in m³/ha/year (Table 3.11).

Table 3.11 Potential annual increase of biomass, calculated in cubic meters.

Forest type	**High forest**	**Coppice forest**	**Total**
Beech forests	38’957.88	53’010.65	**91’968.53**
Mesophilic oak forests	135’721.09	652’314.00	**788’035.09**
Chestnut forests	85.05	122'696.10	**122'781.15**
Mesophilic deciduous forests	14’212.00	51’137.94	**65’349.94**
Hygrophilous forests	65'912.50	1'463.40	**67'375.90**
Holm oak forest	6’292.75	15’840.66	**22’133.41**
Mountain and Mediterranean pine forests	151'301.26	0	**151’301.26**
Wood plantation and reforestation	4’158.20	0	**4'158.20**

In order to guarantee a sustainable level of harvesting, the Guidelines of the Basilicata Region for Forest Management Plans (PAF) indicate that the quantity of wood collected cannot exceed **60%** of the increase for tall woods and **90%** for coppice woods. Therefore, in estimating the residual biomass it must be taken into account that not all forest formations can be considered in the same way and it is necessary to attribute the appropriate percentages to the various forest species (Table 3.12).

In particular, Mediterranean pine forests, mountain pine forests and hygrophilous formations were excluded from this estimate, taking into account the total absence of a local wood market for these species.

Table 3.12 Annual residual biomass that can be harvested distinguished by forest species (%).

Forest Type	**Residual Biomass (Hight forest)**	**Residual Biomass (Coppice forest)**
Beech forests	***8%***	***25%***
Mesophilic oak forests	***15%***	***20%***
Chestnut forests	***15%***	***16%***
Mesophilic deciduous forests	***15%***	***20%***
Hygrophilous forests		
Holm oak forest	***25%***	***32%***
Mountain and Mediterranean pine forests		
Wood plantation and reforestation	***15%***	

Table 3.13 shows the cubic meters of residual biomass potentially produced each year for energy purposes. For the purposes of modeling, only the total values were taken into consideration without considering the distinction by form of forest governance (high forests and coppice).

Table 3.13 Potential annual residual biomass available in Basilicata (m^3).

Forest type	**High forest**	**Coppice forest**	**Total**
Beech forests	1’869.98	11’927.40	**13’797.37**
Mesophilic oak forests	12’214.90	117’416.52	**129’631.42**
Chestnut forests	7.65	17’668.24	**17’675.89**
Mesophilic deciduous forests	1’279.08	9’204.83	**10’483.91**
Hygrophilous forests	0	0	**0**
Holm oak forest	943.91	4’562.11	**5’506.02**
Mountain and Mediterranean pine forests	0	0	**0**
Wood plantation and reforestation	374.24	0.00	**374.24**

The detailed representation of forestry activities was carried out by processing the data of the National Forest Accounting Plan (PNA) relating to the volumes of wood taken from the Lucanian forests divided by forest species considering the Istat time series archive[23] and projecting the estimated values to 2025. The results organized following the classification of the species adopted in the modelling are reported in Table 3.14.

Table 3.14 Cubic meters harvested wood by forest species.

Forest type	***2020***
Beech forests	22'395
Mesophilic oak forests	32'577
Chestnut forests	44'391
Mesophilic deciduous forests	69'804
Hygrophilous forests	0
Holm oak forest	18'877
Mountain and Mediterranean pine forests	2'977
Wood plantation and reforestation	6'990

The average costs relating to the felling, concentration, deforestation, preparation and stacking phases for forest species were deduced from a market survey conducted on a sample of companies operating in the forest sector in Basilicata (Table 3.15).

Table 3.15 Euro per cubic meters of wood by forest species.

Forest type	***Costs***
Beech forests	*€ 37.50*
Mesophilic oak forests	*€ 37.50*
Chestnut forests	*€ 15.00*
Mesophilic deciduous forests	*€ 40.00*
Hygrophilous forests	*€ 0.00*
Holm oak forest	*€ 32.50*
Mountain and Mediterranean pine forests	*€ 12.50*

[23] https://www.istat.it/en/archive/200906

Livestock activities

The size of the farms, described by the **Number of Heads** (cattle, sheep, goats and pigs) present in the Lucanian farms, was estimated based on the annual data provided by Istat[24]. Poultry and horse farms were excluded as they were not significant for the purposes of the analysis, as equine farming represents only by 5% of farms with an average of about 3 animals per farm. The results are resumed in Table 3.16.

Table 3.16 Number of heads classified by species.

	Number of Heads	
Species	***2010***	***2015***
Cattle	90'755	93'564
Sheep	263'007	307'903
Goats	58'802	68'962
Pigs	84'838	80'601
Total	**644'113**	**497'402**

In modelling livestock activities, the variable number of heads coincides with both the demand for end use and the output of the dummy process.

The potential of manure that can be used for the biogas production was calculated based on the number of animals present for the different species and a specific rate of manure production (average tons per year per head) provided by the literature (Table 3.17). Specifically, 1.69 for cattle, 0.21 for pigs and 0.28 for goats and sheep. It was also considered that it is possible to recover 85% of manure for pigs reared intensively and 25% in the case of cattle, sheep and goats, whose breeding is widespread in Basilicata (Statuto, 2019).

[24] http://dati.istat.it/Index.aspx?QueryId=33654

Table 3.17 Potential dry matter by livestock species (tons).

Type of livestock	2010	2015
Cattle	38’343.99	39’530.79
Sheep	7’364.20	8’621.28
Goats	1’646.46	1’930.94
Pigs	15’143.58	14’387.28

Similarly to agricultural processes, the specific production costs (net of water and energy expenditure) were estimated with reference to the microdata data of the FADN survey. The obtained results, both for 2010 and for 2015, were compared to other sources in the literature to highlight anomalies for some of the species analyzed.

Therefore, only the data published on the online database[25] referring to the euro per Livestock Unit (LU) have been utilised (Table 3.18).

Table 3.18 Specific production costs by livestock species (€/LU).

Type of livestock	2010
Cattle	539
Sheeps	365
Goats	395
Pigs	586

The data collected from values for LU were reported to the Head of livestock through specific conversion factors. They were then reduced by the percentage of expenditure attributable to the water and energy components. This value, according to the microdata processed from the FADN survey, was found to be around 5%. The final results obtained are shown in Table 3.19. The green column shows the values used for the analysis, namely the costs net of energy and water.

Table 3.19 Specific production costs by livestock species (Euro per Head).

Type of livestock	€/Head	€/Head
Cattle	395.59	***375.81***
Sheeps	34.61	***33.22***
Goats	37.26	***35.76***
Pigs	115.42	***108.50***

[25] http://arearica.crea.gov.it/report_e.php

Supply

Water

The choice of irrigation processes was made in accordance with what is reported in the literature for the Basilicata region (INEA, 2009).

Irrigation is a practice widely used by about one fifth of companies with an irrigated regional agricultural area equal to 8% of the regional territory in 2010 (Istat, 2010).

Irrigated agriculture in Basilicata has developed unevenly in the region due to the different operating conditions linked to both the pedoclimatic and morphological conditions and the socio-cultural characteristics of the different areas. The areas of the Basilicata region most suited to irrigation are the Metapontino plain, the Lavellese and the Upper Agri Valley. The irrigation practice is mainly associated with traditional production practices, with the larger irrigation farms those in which the portion of UAA that is not irrigated or non-irrigable is greater. In contrast, smaller irrigation farms allocate a relatively larger share of land than their size to irrigation practices.

Crops intended for irrigation can be divided into three categories:

1. Fully irrigated (horticultural crops, vines for table grapes, citrus groves);
2. Partially irrigated (olive trees, vines and some fruit trees);
3. Not irrigated (cereals, forage, crops and grain legumes).

In view of what has just been described, water consumption for irrigation for Horticulture, Viticulture, Olive growing, Orchards and Citrus grove process was calculated by using the data provided by the latest Istat Agricultural Census (2010)[26], leaving out those types of crops that adopt backup irrigation when necessary.

The Census provided data on the annual volumes in cubic meters of irrigated water and the hectares of irrigated area by crops (both information is present for both organic and conventional practices). By a ratio between the two values, it was possible to obtain the consumption per hectare for the analysed crops (table 3.20).

Table 3.20 Estimated volumes of irrigation water by crops (m3/ha).

m3/ha	***Horticulture***	***Viticulture***	***Olive growing***	***Orchards and citrus groves***
Organic	2’698	1’606	3’102	3’737
Non-Organic	2’764	1’692	3’136	4’390
Total	***5’461***	***3’298***	***6’239***	***8’127***

For breeding, by taking into account literature references (CRPA, 2005; CReNBA, 2020) the annual per capita water consumption was estimated starting from the average daily consumption calculated for both livestock watering facilities and stable management, divided by species (Table 3.21).

Table 3.21 Estimated water consumption per head distinguished by species.

	Water consumption	
Species	***Dailly litre/Head***	***Annul m3/Head***
Cattle	157	57
Sheep	12	4
Goats	12	4
Pigs	70	26

The cost of irrigation water for agriculture was set equal to the average price applied by the Reclamation Authority (0.47 Euro/m^3), while the cost provided by the Authority for Waste and Water Resources of the Basilicata Region (0.73 Euro/m^3) was applied for livestock.

The values of rainwater were taken from the agroclimatic observatory of the Ministry Of Agricultural, Food and Forestry Policies[27]. The values expressed in mm for the Basilicata region are reported in table 3.22. It was assumed that they are constant throughout the entire regional territory.

Table 3.22 Rainwater (mm/year).

	2010	**2011**	**2015**
Rainwater (mm)	*893*	*681*	*734*

[26] The data are available on Istat web site (http://dati.istat.it/Index.aspx?QueryId=33654), specifically in Agriculture section=>Census2010=>Crops=> Farms, irrigated area and volumes

[27] https://www.politicheagricole.it/flex/FixedPages/Common/miepfy700_regioni.php/L/IT?name=00017.

Fertilisers

The quantities of fertilizers used in 2010 (reference year of the TIMES Land-WEF model) were estimated starting from the microdata provided by the FADN census relating to the use of fertilizers, (nitrogen (N), phosphorus (P) and potassium (K), distributed per hectare of cultivated area).

As described above for the evaluation of crops costs, using the identification codes of the various plant species, the sample units for fertilizers (no. 1156) were then classified according to the 8 categories of agricultural activities considered by the model.

Within the available sample the code associated with each company made it possible to identify the companies that do not carry out any organic process and those that instead practice organic farming in whole or in part.

Furthermore, since the fertilizers within the sample are expressed either in hectoliters or in quintals, it was necessary to convert the quantities expressed from hectoliters to quintals.

In this way, for the entire sample, all the useful information was extracted to have a complete overview of fertilizer consumption.

Finally, the data of the sample of companies were extended to the entire Basilicata Region (statistical universe target of the FADN sample) by a weighting procedure of the results, on the basis of which each company surveyed in the FADN is assigned a sample base weight[28].

The results obtained on the entire sample were then summarized through a pivot table in order to obtain the values of tons of N, P, K per hectare for each type of crop analyzed (Table 3.23).

[28] Methodological note on the use of statistical weights in FADN survey is available on CREA website: https://rica.crea.gov.it/ponderazione-dei-risultati-27.php

Table 3.23 Estimate of fertilizers (N, P, K) by crops (tons per hectare).Following the same calculation procedure, the results for horticulture were extracted from the sample

	N_tons_hectare	P_tons_hectare	K_tons_hectare
Cereals			
Non Organic	0.04346	0.00116	0.00030
Organic	0.03752	0.00025	0.00037
Forage			
Non Organic	0.03396	0.00096	0.00030
Organic	0.02568	0.00000	0.00000
Orchards and citrus groves			
Non Organic	0.08262	0.02273	0.03282
Organic	0.07202	0.02779	0.03784
Olive growing			
Non Organic	0.05979	0.00957	0.00790
Organic	0.03861	0.00300	0.00335
Other arable crops			
Non Organic	0.04325	000046	0
Organic	0.07358	0	0
Permanent meadows and pastures			
Non Organic	0.02088	0.00003	0.00004
Viticulture			
Non Organic	0.07903	0.01529	0.01413
Organic	0.06073	0.00838	0.00587

separately as it was also necessary to analyze the subcategories of cultivationprocess "in open field " and "in greenhouse". The results are reported in Table 3.24.

Table 3.24 Estimate of fertilizers (N, P, K) for horticulture (tons per hectare)

	N_tons_hectare	**P_tons_hectare**	**K_tons_hectare**
Horticulture - Non Organic			
in greenhouse	0.388	0.109	0.148
in open field	0.052	0.013	0.013
Horticulture - Organic			
in open field	0.035	0.019	0.029

Using the same methodology for the analysis of the data relating to the FADN sample census for the year 2015, various anomalies were found; therefore, it was decided to use only the data relating to 2010.

The average annual prices of fertilizers (nitrogen, phosphate and potassium) for 2010 and 2015 were estimated taking into account the data published in the fortnightly bulletins of the Turin Chamber of Commerce[29], the only reference that made available the time series (Table 3.25). Given the availability of data as a further benchmark, it was also calculated the average annual price relating to the year 2020 (latest available).

Table 3.25 Average annual prices of fertilizers (Euro/ton).

	2010	**2015**	**2020**
Nitrogen fertilizers	113.73	146.07	115.73
Phosphate fertilizers	466.46	522.50	427.50
Potassium fertilizers	725.94	752.29	668.33

[29] https://www.to.camcom.it/archivio-listini-anni-precedenti

The characterization of the use of **pesticides** with reference to the different agricultural activities is rather complex given the variety of products available (fungicides, herbicides, acaricides, etc.), the disparity of units of measurement and use with respect to cultivation processes.

An estimate of the use of substances used for crop protection was therefore made for the year 2010 using as basic information the quantity of active substances contained in the pesticides distributed for agricultural use in the Basilicata region[30].

First, a distinction was made between the quantity of active substances contained in the chemicals used in traditional cultivation processes and those allowed in organic farming (Table 3.26).

Table 3.26 Tons of active substances contained in pesticides, distinguished by chemical and organic typologies.

	Tons
Chemical substances	780
Organic substances	9.45

The obtained total quantities were distributed among the different analyzed crops by a weighting procedure based on costs for crop protection (Euro/ton) of the main productions (processed starting from FADN microdata) and tons of annual main productions (processed by Istat data). The results are reported in Table 3.27.

[30] The data refer to an Istat report on "The distribution of plant protection products for agricultural use" available online: https://www4.istat.it/it/archivio/44206

Table 3.27 Tons of active substances distributed by crops. (Non organic process).

	Tons active substances
Cereals	74.49
Forage	0
Horticulture- in field	69.57
Horticulture- in greenhouse	83.59
Viticulture	130.08
Olive growing	55.32
Orchards and citrus groves	365.61
Permanent meadows	1.36

The same calculation method was applied for the distribution of the tonnes of organic active ingredients, the details and the results obtained are reported in the following capture of excel sheet (Table 3.28).

Table 3.28 Tons of active substances distributed by crops. (Organic process).

	Tons active substances
Cereals	0.53
Forage	0
Horticulture- in field	1.98
Horticulture- in greenhouse	0
Viticulture	0.40
Olive growing	0.14
Orchards and citrus groves	6.41
Permanent meadows	0

Diesel consumption for the various crop categories was calculated starting from the data reported in the documentation of the Basilicata Region relating to the demand of agricultural fuel at subsidized prices[31] for the year 2010 (average consumption of agricultural fuel per hectare).

The document provides the average consumption values of litres of diesel per hectare, for agricultural processes (plowing, sowing, fertilization,…) distinguished by crop type.

The estimate of consumption was carried out by distinguishing the cultivation processes and the irrigation phases and further distinguishing between conventional and organic agriculture. In particular, the consumption for irrigation was considered the same for both cultivation methods while for the cultivation processes a consumption lower than -40% was estimated for organic compared to conventional agriculture, justified by a reduction in the processing phases and use of fertilizers (Alonso, 2010; Pimentel, 2014; Dal Ferro, 2017). The obtained results are reported in Table 3.29.

Table 3.29 Estimated annual consumption (in liters) of diesel per hectare for irrigation and cultivation process.

	Cereals	***Forage***	***Other arable crops***	***Hort.- in the field***	***Hort.- in greenhouse***	***Viticulture***	***Olive growing***	***Orchards and citrus groves***	***Permanent meadows and pastures***	**Total**
Organic										
Cultivation process	146	176	166	232		268	241	317	100	**1'647**
Irrigation	100	140	132	216		400	400	400		**1'788**
Non Organic										
Cultivation process	244	294	277	387	378	447	402	528	242	**3'199**
Irrigation	100	140	132	216	216	400	400	400		**2'004**

31 https://www.regione.basilicata.it/giunta/site/giunta/department.jsp?dep=100049&area=242342&otype=1057&id=242591

In addition, the estimate of consumption per head of livestock for the species considered by the model (cattle, sheep, goats and pigs) was also carried out using the average data of regional legislation (Table 3.30).

Table 3.30 Estimated annual consumption (in litres) of diesel per head of livestock.

	l/Head
Cattle	60
Sheep	10
Goats	10
Pigs	31

In the case of agricultural activities, the estimated consumption was multiplied by the hectares (calculated on Istat data) associated with the crop types in order to obtain total values. For farms, however, the unit data were multiplied by the number of heads per species (calculated on Istat data). Once these values were obtained, they were converted into PJ, through specific conversion factors. It was thus possible to harmonize the results obtained for each single category with the aggregate demand for diesel provided by Regional Energy Plan (PIEAR)[32]for the agricultural sector (1.74 PJ for the year 2010). In Tables 3.31 and 3.32 the obtained results for crops typologies and livestock species are reported.

Table 3.31 Estimated annual consumption of diesel (PJ) by crops typologies (year 2010).

	Cereals	***Forage***	***Other arable crops***	***Hort.- in the field***	***Hort.- in greenhouse***	***Viticulture***	***Olive growing***	***Orchards and citrus groves***	***Permanent meadows and pastures***	**Total**
Organic	0.05	0.02	0.00	0.02	0.00	0.00	0.02	0.04	0.04	**0.19**
Non Organic	0.61	0.15	0.01	0.10	0.01	0.04	0.03	0.27	0.12	**1.33**

Table 3.32 Estimated annual consumption of diesel (PJ) by livestock species (year 2010).

	PJ/year
Cattle	0.09
Sheep	0.07
Goas	0.02
Pigs	0.04
Total	**0.22**

The same calculation method was applied to process the data for year 2015; the results are reported in Tables 3.33 and 3.34.

Table 3.33 Estimated annual consumption of diesel (PJ) by crops (year 2015).

	Cereals	***Forage***	***Other arable crops***	***Hort.- in the field***	***Hort.- in greenhouse***	***Viticulture***	***Olive growing***	***Orchards and citrus groves***	***Permanent meadows and pastures***	**Total**
Organic	0.04	0.04	0.00	0.01	0.00	0.00	0.01	0.03	0.04	**0.18**
Non Organic	0.63	0.14	0.01	0.09	0.02	0.02	0.02	0.24	0.13	**1.30**

Table 3.34 Estimated annual consumption of diesel (PJ) by livestock species (year 2015).

	PJ/year
Cattle	0.07
Sheep	0.00
Goas	0.05
Pigs	0.01
Total	**0.13**

The average annual prices (2010, 2015) of diesel for agricultural use were estimated on the basis of fortnightly bulletins relating to the prices of petroleum products published by the Chamber of Commerce of Terni, the only reference that made available the time series (Table 3.35).

Table 3.35 Average annual prices of agricultural diesel (€/litre).

2010	0.79
2015	0.69
2020	0.71

[32] https://www.regione.basilicata.it/giunta/files/docs/DOCUMENT_FILE_543546.pdf

To complete the characterization of energy supply, consumption of electricity, natural gas and LPG is mainly attributed to livestock farming. For agriculture activity, it was considered only electricity consumption for greenhouse horticulture. The estimate of electricity consumption related to the cultivation of vegetables was obtained considering an average value of about 60-80 kWh/m^2, reported in the scientific literature for structures located in the Mediterranean area (De Pascale, 2008).

The quantification of energy needs of the national livestock sector or of its territorial subsets, as also emerges from an ENEA report of 2014, and is rather complex due to the non-homogeneity of the livestock production system both in relation to the basic structure and to the production strategies.

Furthermore, the technologies of the production process, on which the extent of energy consumption largely depends, vary considerably according to the structural and production characteristics of farms.

In the absence of specific data, it was therefore decided to use the average consumption values referring to the Italian regions where livestock farming represents a significant activity, such as Emilia Romagna, which are reliable and accurate, although not exactly reflecting the reality of Basilicata (Table 3.36).

Table 3.36 Estimated annual consumption of electricity, natural gas and LPG by head of livestock species.

	Electricity (GWh/head)	**Natural gas (l/head)**	**LPG (l/head)**
Cattle	0.00051	28000	92.00
Sheep	0.00007	5250	17.25
Goats	0.00007	5250	17.25
Pigs	0.00015	17600	16.00

As done for diesel, the estimated consumption was multiplied by the number of the livestock head in order to obtain total values. For greenhouse horticulture, the unit data were multiplied by the hectare. Once these values were obtained, they were converted into PJ, through specific conversion factors. In this way, it was thus possible to harmonize the results obtained for each single category with the aggregate demand for electricity, natural gas and LPG provided by Regional Energy Plan (PIEAR) for the agricultural sector. Namely, 0.23 PJ (2010) and 0.23 PJ (2015) for electricity, 0.04 PJ (2010) and 0.03PJ (2015) for natural gas.

As regards costs, the price of electricity (Euro/MWh) for the years 2010 and 2015 was estimated on the basis of the data reported in the Annual Report of the Energy Services Operator (GSE) - €/MWh (2010), €/MWh (2015) while for LPG the average annual cost published by the Ministry of Ecological Transition.

The information contained in the National Forest Accounting Plan (PAN) was also used to estimate the CO_2 absorbed by the forests of the Basilicata region, i.e. the data relating to carbon sinks calculated on a regional scale using the *forest* model (according to the guidelines suggested by the IPCC).

This model calculates the carbon stocks from the aboveground biomass for each forest species on an annual basis by summing the net annual increase and subtracting the losses associated with harvesting (industrial logs and firewood), forest fires and other causes (drought, pastures, the wind).

The data are estimated starting from 2000 and they are projected up to 2025 with reference to the official ISPRA and Istat 2009 statistics.

The values reported in the document were adapted to the forest categories considered in the TIMES Land-WEF model, reported to unit values (tons of carbon per hectare) and then the values of the absorbed carbon were calculated as the difference between the total carbon of the year considered and the total carbon of the previous year. The obtained data for the fixed carbon were reported to the CO_2 values through a conversion ratio of 3.67.

The average values, calculated over the period 2000-2010, are shown in Table 3.37.

Table 3.37 Estimated average annual absorbed CO_2 (t/ha) by forest species in Basilicata.

Forest type	
Beech forests	5.43
Mesophilic oak forests	7.09
Chestnut forests	6.80
Mesophilic deciduous forests	4.35
Hygrophilous forests	4.35
Holm oak forest	7.09
Mountain and Mediterranean pine forests	9.22
Wood plantation and reforestation	7.12

Finally, to estimate the total based on the data available in literature (CREA, 2016), the average annual requirement for the maintenance of individual animals was estimated to be equal to 1600 Forage Units (FU) for cattle, 559 FU for sheep and 889 FU for goats.

3.4 The TIMES Basilicata Land-WEF basic assumptions

The time horizon analyzed by TIMES Land-WEF model covers a period of 52 years, from 2010, the model base year, to 2060, subdivided into a first period of two years and ten periods of five years each (model's time slices), considering 2030 as a milestone. This long-term time horizon makes it possible to evaluate the effects of the strategies for achieving the targets of the 2030 Agenda beyond the year 2030 and to trace the path towards the Energy Roadmap 2050 through a scenario analysis. Furthermore, from a modeling point of view, the choice of a time horizon that goes beyond 2030 derives from the need to harmonize the timing of the TIMES-WEF to the TIMES Basilicata energy system module to allow its future integration and increase the reliability of the solutions in a long-term perspective.

The model's base year, 2010, represents the year in which the model is calibrated based on statistical data directly taken or elaborated from national databases, regional sources and other available sources of data. The model was also calibrated for the years 2011, 2015 and 2020 on the basis of the available statistical values. The definition of different timeslices allows taking into account the variability of some commodities (for example electricity and water) both at a seasonal (Spring, Summer, Fall and winter) and daily (Day, Night and Peak) level (Figure 3.14).

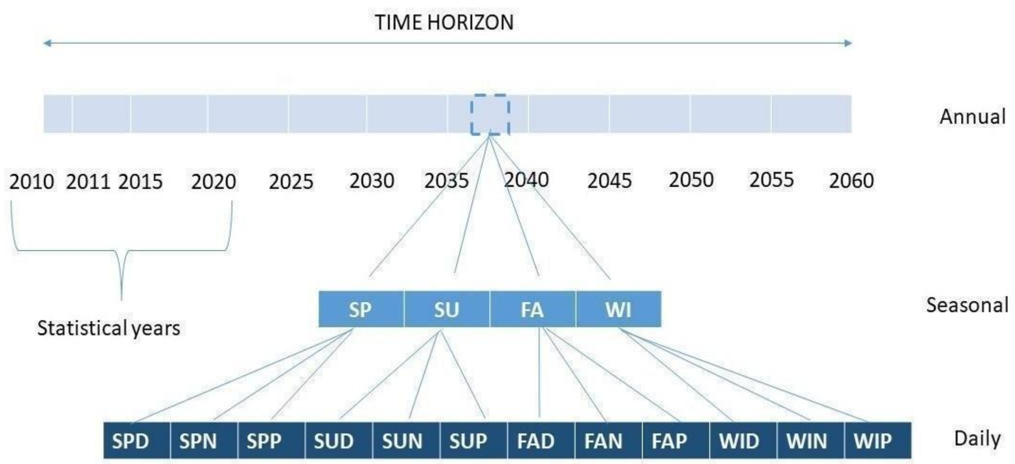

Figure 3.14 Timeslices of the TIMES Land-WEF model. Legend: SP (Spring) – SU (Summer) – FA (Fall) – WI (Winter) – SPD (Spring Day) – SPN (Spring Night) – SPP (Spring Peak) – SUD (Summer Day) – SUN (Summer Night) – SUP (Summer Night) – FAD (Fall Day) – FAN (Fall Night) – FAP (Fall Peak) – WID (Winter Day) – WIN (Winter Night) – WIP (Winter Peak).

The structure of the TIMES Land-WEF model is composed of three main set of Excel spreadsheets (Figure 3.15):

Four base year templates: **PRD.xls** file with processes and commodities for agricultural production, **LIV.xls** file with processes and commodities for livestock, **SUP.xls** file with supply of water both for irrigation and for livestock, of energy, of fertilizers, of crop defence, **FOR.xls** with processes and commodities for forest modelling.

A "subres new-techs database", which contain the technologies of agricultural production with the variation of some fundamental parameters for the scenario analysis with respect to the values assumed in the reference years

Scenario files, which contain emission factors of the main agricultural sources and all the main coherent assumptions necessary to build up alternative scenarios: future trajectories of demand (Demand Projections) and exogenous constraints (User Constraints).

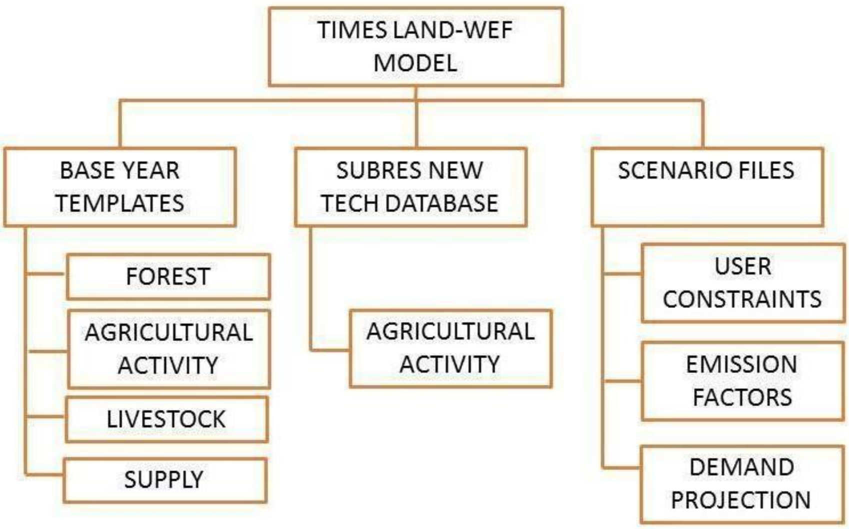

Figure 3.15 Data input structure TIMES Land-WEF model.

Concerning the main assumptions, the final demand is considered constant over the entire time horizon, both for agricultural land use and forestry and for livestock heads.

In Table 3.38 the main assumptions for the construction of the TIMES land WEF model are reported.

Table 3.38 Main assumptions of the TIMES Basilicata Land-WEF model.

Categories	**Basic Assumptions**
Land use	In 2060 the variation in land use of each crop production is between -10% and + 10% of the values assumed in 2020
	The total land use of 2020 is considered constant on the entire time horizon
Crop production	Diesel consumption per unit of product obtained in the base year is considered constant over the entire time horizon for all typologies
	The input of three fertilizers (nitrogen, phosphate, and potassium) per unit of product obtained in the base year is considered constant over the entire time horizon
	As for fertilizers, the input of active substances for crop protection per unit of product obtained in the base year is considered constant over the entire time horizon both for conventional and organic productions.
Livestock	Electricity, natural gas and diesel consumption per head unit obtained in the base year are considered constant over the entire time horizon

3.5 The TIMES Basilicata-Land-WEF model calibration

The first fundamental step after the implementation of any TIMES-based model is its calibration to the statistics and validation of results in a status-quo long term development through an iterative process of comparison of the data with the model's outputs, and subsequent revision of the model where necessary, until the achievement of accurate and consistent results.

In fact, after the definition of the structure of the TIMES Land WEF model of Basilicata and the related input data, the calibration was carried out taking into account the statistical data of the base year (2010), the reference year of the model, and the years 2011, 2015 and 2020, for which information was available. In the following the results of the calibration runs are discussed in details with reference to model's commodities.

Figure 3.16 shows the diesel consumption of the different agricultural categories which is higher in conventional crops than in organic crops. In particular, conventional cereals show the highest values (**0.61 PJ**), followed by conventional forage (**0.15 PJ**), conventional orchards and citrus groves (**0.15 PJ**), conventional permanent meadows and pastures (**0.12 PJ**) and irrigation of conventional orchards and citrus groves (**0.12 PJ**). Among the organic crops, cereals and permanent meadows and pastures show the highest values, respectively **0.05 PJ** and **0.04 PJ**.

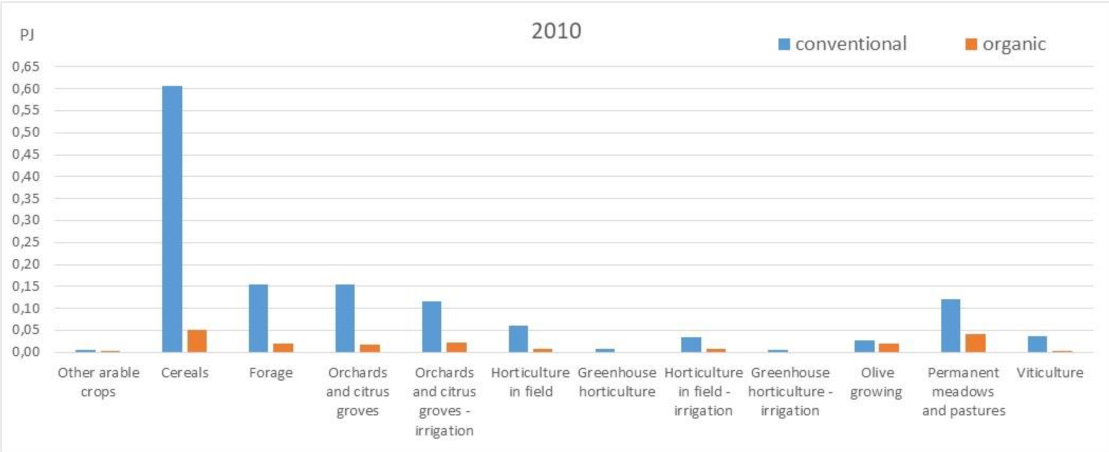

Figure 3.16 Diesel consumption for crop category– base year (2010).

As concerns livestock (figure 3.17), in the base year cattle has the highest consumption of electricity (**0.11 PJ**) and diesel (**0.09 PJ**). Sheep and goats are characterised by identical consumption of electricity and diesel. In fact, electricity and diesel consumption are **0.019 PJ** for goats and **0.068 PJ** for sheep.

As for livestock, cattle have the highest consumption of electricity (**0.11 PJ**) and diesel (**0.09 PJ**) in the year 2010, while sheep and goats are characterized by identical consumption of electricity and diesel fuel of **0.068 PJ** for sheep **and 0.019 PJ** for goats.

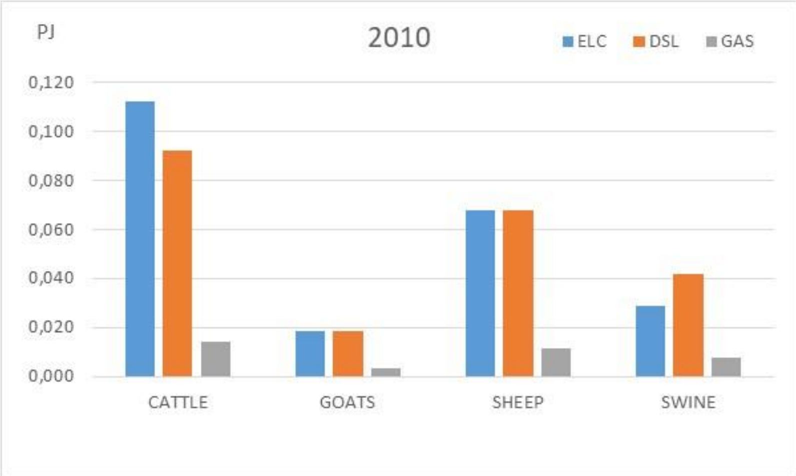

Figure 3.17 Energy consumption for livestock –year 2010. Legend: ELC [Electricity], DSL [Diesel], GAS [Natural gas]

Figure 3.18 shows irrigation water for orchards and citrus groves and horticulture for the years 2010, 2011, 2015, 2020. In line with the data, irrigation water for conventional orchards and citrus groves goes from **72 Mm^3** in 2010 to **52 Mm^3** in 2020 while for organic orchards and citrus groves it is **0.13 Mm^3** in 2011 and **0.10 Mm^3** in 2015. Water irrigation for conventional horticulture in field goes from **25 Mm^3** in 2010 to **16 Mm^3** in 2020 reaching its maximum (**28 Mm^3**) in 2011. For conventional greenhouse horticulture, the values go from **2.1 Mm^3** in 2010 to **1.3 Mm^3** in 2020 and for organic horticulture in the field from **5 Mm^3** in 2010 to **10 Mm^3** in 2020.

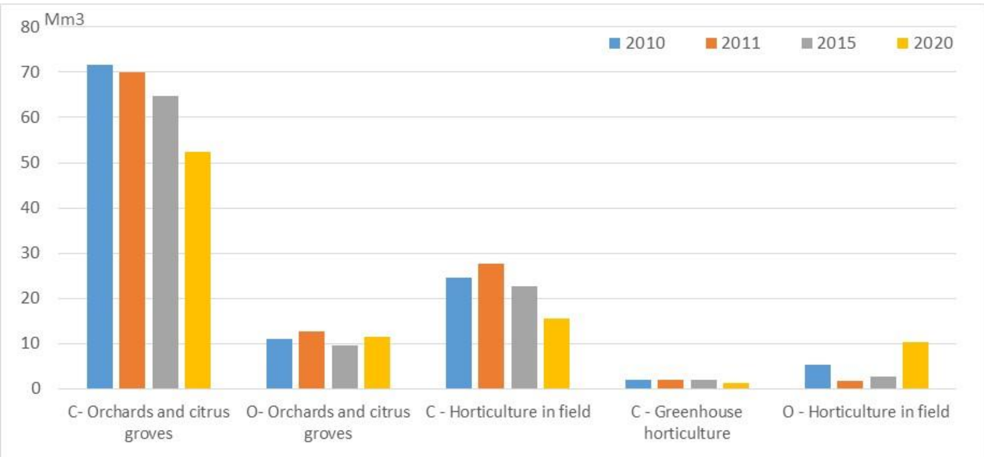

Figure 3.18 Irrigation water for farming in 2010, 2011, 2015 and 2020. Legend: C – Conventional, O - Organic

As for livestock (Figure 3.19), cattle record the highest consumption of water going from **4.93 Mm³** in 2010 to **5.71 Mm³** in 2020. Goats and sheep show a decreasing trend (respectively from 0.45 Mm3 in 2010 to **0.27 Mm³** in 2020 and from **1.66 Mm³** in 2010 to **1.10 Mm³** in 2020), while the water consumption of swine goes from **1.93 Mm³** in 2010 to **2 Mm³** in 2020.

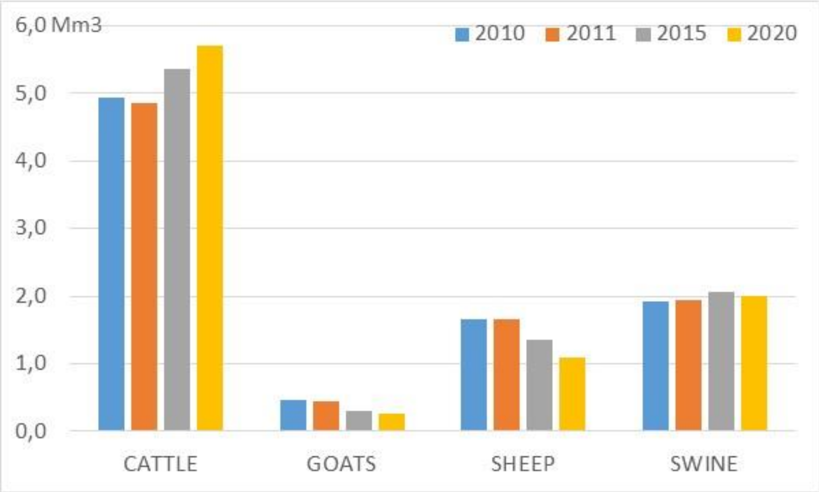

Figure 3.19 Water consumption for livestock – years 2010, 2011, 2015 and 2020.

As regards the use of nitrogen fertilizers (Figure 3.20), the highest values are found in conventional cereals with a maximum of **7'619 tons** in 2015. Conventional permanent meadows and pastures consume about **3'000 tons** (**2'856 tons** in 2010, **3'057 tons** in 2011, **2'872 tons** in 2015 and **3'201 tons** in 2020), while there is no consumption of for permanent organic meadows and pastures.

In the case of organic crops, the total consumption of nitrogen fertilizers is always lower than the consumption of the corresponding conventional crops and only cereals show values exceeding one thousand tons (**1'661 tons** in 2010, **1'728 tons** in 2011 and **1'829 tons** in 2020.

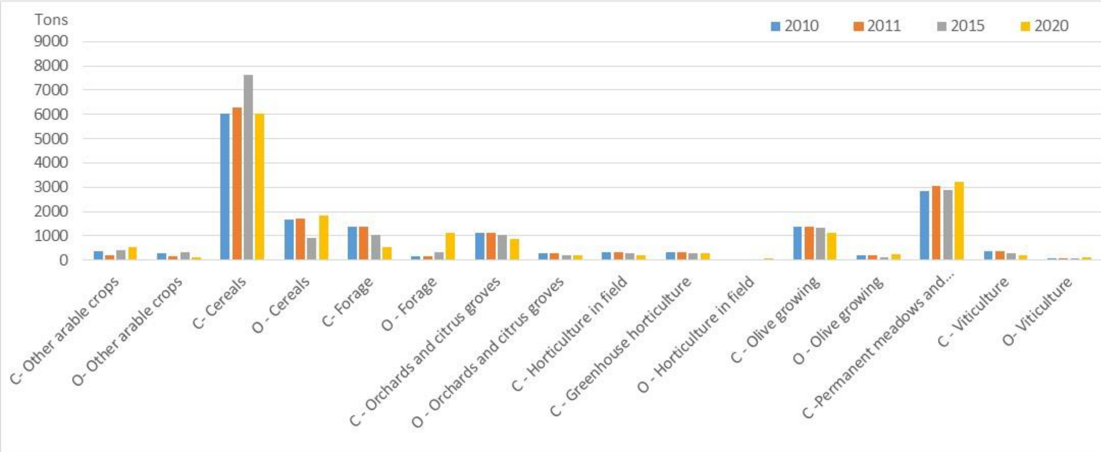

Figure 3.20 Use of nitrogen fertilisers for each crop – 2010, 2011, 2015 and 2020. Legend: C – Conventional, O – Organic.

As for phosphate fertilizers (Figure 3.21), the highest values are recorded in conventional orchards and citrus groves (**306 tons** in 2010, **310 tons** in 2011, **291 tons** in 2015 and **234 tons** in 2020. Other crops characterized by high levels of consumption of fertilizer phosphates are conventional olive growing (**223 tons** in 2010, **220 tons** in 2011, **214 tons** in 2015 and **179 tons** in 2020) and conventional cereals (**160 tons** in 2010, **167 tons** in 2011, **203 tons** in 2015 and **161 tons** in 2020).

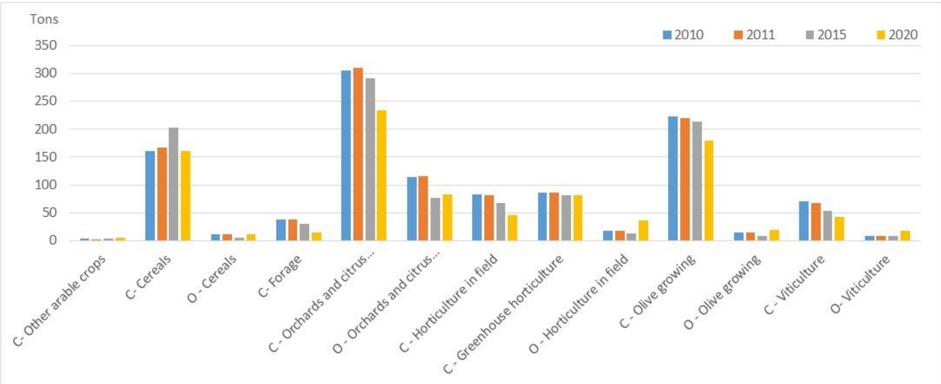

Figure 3.21 Use of Phosphate fertilisers for each crop – 2010, 2011, 2015 and 2020. Legend: C – Conventional, O – Organic.

As in the case of phosphate fertilizers, potash fertilizers (Figure 3.22) also have the highest consumption with conventional orchards and citrus groves (**442 tons** in 2010, **448 tons** in 2011, **420 tons** in 2015 and **339 tons** in 2020) followed by conventional olive growing (**184 tons** in 2010, **182 tons** in 2011, **177 tons** in 2015 and **148 tons** in 2020).

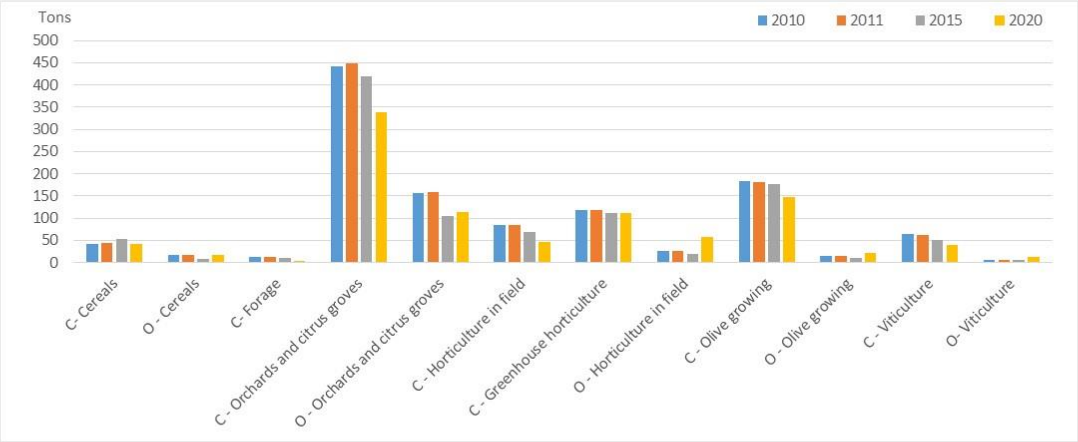

Figure 3.22 Use of Potash fertilisers for each crop – 2010, 2011, 2015 and 2020. Legend: C – Conventional, O – Organic.

Conventional orchards and citrus groves record the highest consumption of active substances for the protection conventional crop (**288 tons** in 2010, **292 tons** in 2011, **274 tons** in 2015 and **221 tons** in 2020), followed by conventional olive growing (**139 tons** in 2010, **138 tons** in 2011, **134 tons** in 2015 and **112 tons** in 2020), conventional greenhouse horticulture (**106 tons** in 2010, **106 tons** in 2011, conventional viticulture (**107 tons** in 2010, **104 tons** in 2011, **82 tons** in 2015 and **65 tons** in 2020) and conventional cereals (**83 tons** in 2010, **86 tons** in 2011, **104 tons** in 2015 and **83 tons** in 2020), as shown in Figure 3.23. The use of active substances for crop protection is very low for conventional other arable crops and conventional permanent meadows and pastures.

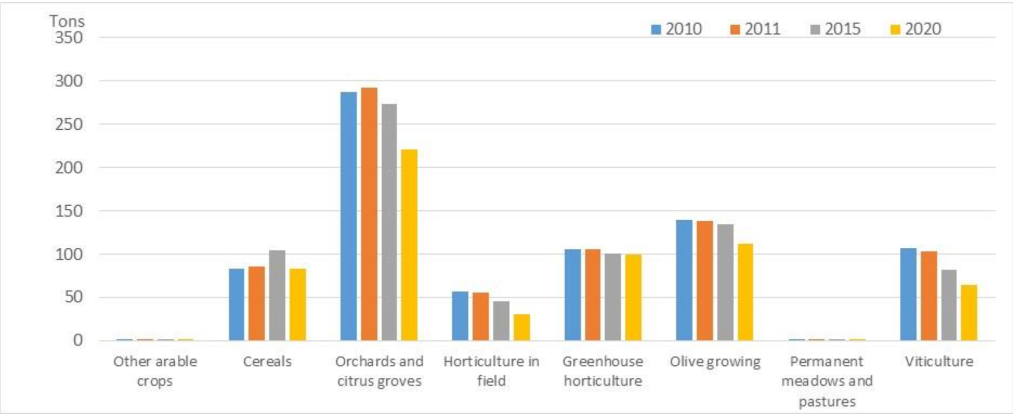

Figure 3.23 Use of active substances for conventional crop protection – 2010, 2011, 2015 and 2020.

The use of active substances for the protection of organic crop is much lower than that of conventional crops (Figure 3.24). The highest values are found for organic orchards and citrus groves and organic horticulture in field have (respectively **5.4 tons** in 2010, **5.4 tons** in 2011, **3.6 tons** in 2015, **3.9 tons** in 2020, and **2.7 tons** in 2010, **2.7 tons** in 2011,

2 tons in 2015 and **5.6 tons** in 2020).

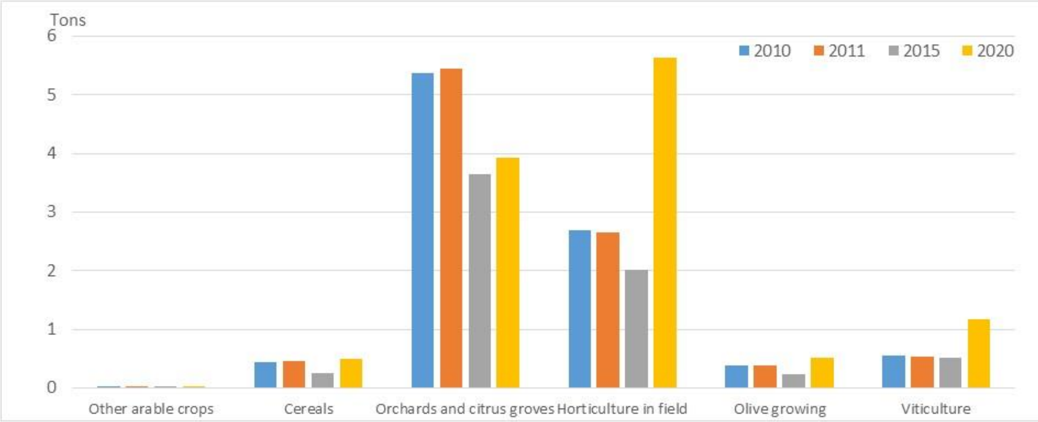

Figure 3.24 Use of active substances for organic crop protection – 2010, 2011, 2015 and 2020.

Regarding waste production (Figure 3.25), conventional cereals show the highest values (**311’264 tons** in 2010, **323’726 tons** in 2011, **392’964 tons** in 2015 and **311’598 tons** in 2020), followed by organic cereals (**99’258 tons** in 2010, **103’232 tons** in 2011, **55’028 tons** in 2015 and **109’273 tons** in 2020).

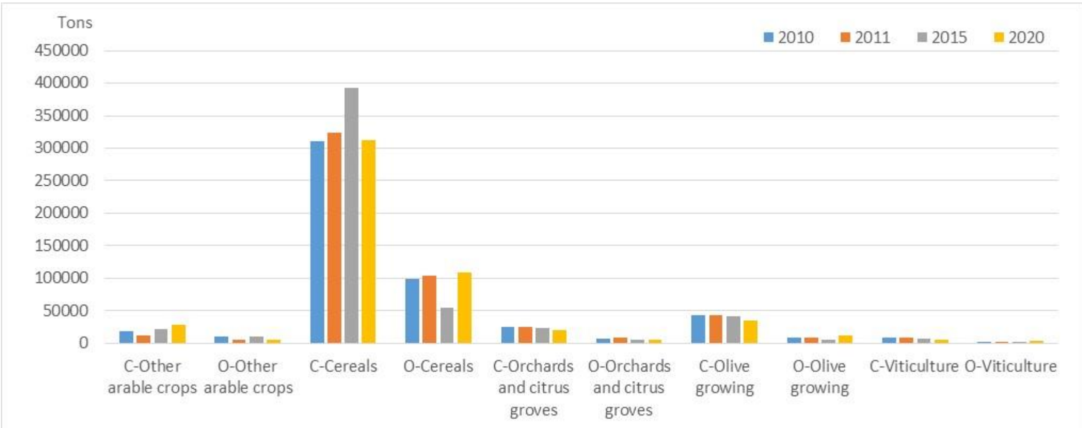

Figure 3.25 Waste production by crops (tons) – 2010, 2011, 2015 and 2020. Legend: C – Conventional, O – Organic.

In livestock, the production of waste by cattle shows the highest values and an increasing trend, going from **36’340 tons** in 2010 to **54’851 tons** in 2020 (Figure 3.26). On the contrary, goats and sheep show a decrease in the production of waste from 2010 to 2020. In particular, waste production by goats goes from **2’902 tons** in 2010 to **1’717 tons** in 2020, while waste production by sheep goes from **10’611 tons** in 2010 to **7’002 tons** in 2020. Waste production by swine fluctuates between **13’474 tons** and **14’387 tons**, reaching the highest value in 2015.

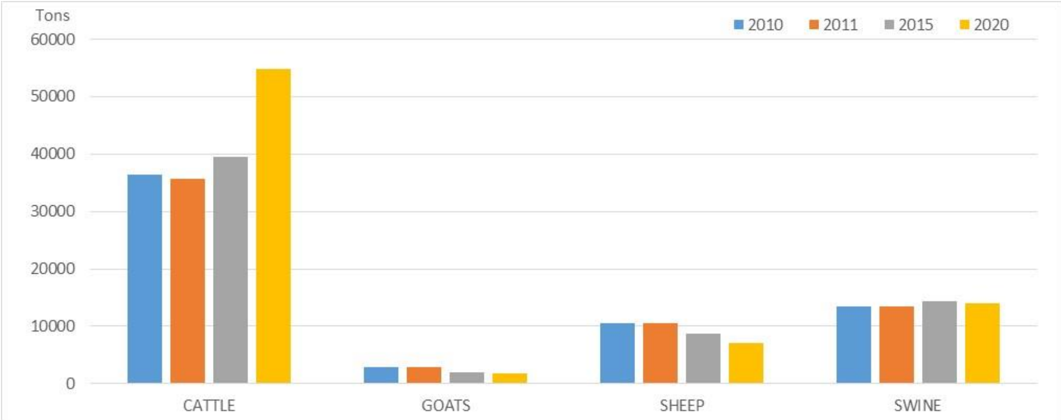

Figure 3.26 Waste production by livestock (tons) – 2010, 2011, 2015 and 2020.

As regards, CO_2 emissions the total is **121 ktons** in year 2010, **123 ktons** in 2011, **117 ktons** in 2015 and **110 ktons** in 2020. In 2010, the base year, **77%** of CO_2 emissions are due to crop production, **13%** to livestock and **11%** to energy consumption for irrigation. In 2020, this distribution slightly changes with a of **80%** share from crop production, **12%** from livestock and **8%** from irrigation water use.

In crop production (Figure 3.27), conventional cereals have the highest CO_2 emissions (**42 ktons** in 2010, **44 ktons** in 2011 e 2015, **35 ktons** in 2020), followed by conventional orchards and citrus groves (**11 ktons** in 2010 and 2011, **10 ktons** in 2015 and **8 ktons** in 2020), conventional forage (**11 ktons** in 2010 and 2011, **10 ktons** in 2015 and **5 ktons** in 2020) and conventional permanent meadows and pastures (**8 ktons** in 2010, **9 ktons** in 2011 and 2015 and **10 ktons** in 2020). CO_2 emissions from conventional and organic other arable crops, conventional greenhouse horticulture, organic horticulture in field and organic viticulture are negligible.

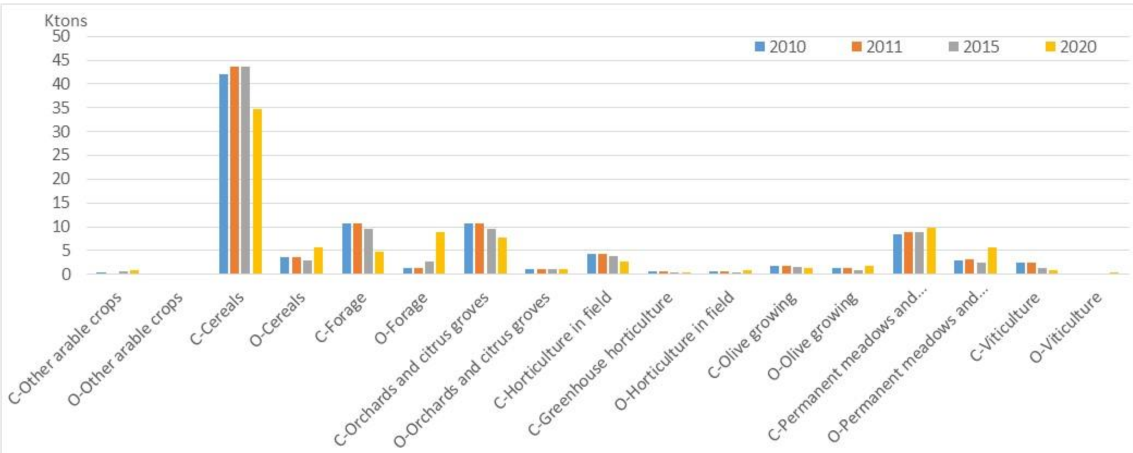

Figure 3.27 CO_2 emissions by crops (ktons) – 2010, 2011, 2015 and 2020. Legend: C – Conventional, O-organic.

CO_2 emissions from cattle oscillate between **6.3 ktons** and **6.9 ktons** reaching the highest value in 2015 (Figure 3.28). CO_2 emissions from sheep decrease from **4.7 ktons** in 2010 to **2.8 ktons** in 2020, while CO_2 emissions from goats decrease from **1.3 ktons** in 2010 to **0.7 ktons** in 2020. CO_2 emissions from swine are around **3 ktons.**

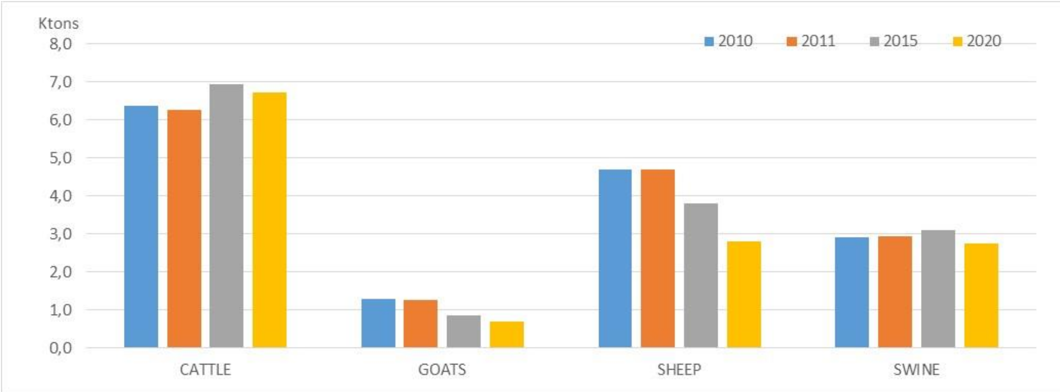

Figure 3.28 CO_2 emissions by livestock (ktons) – 2010, 2011, 2015 and 2020.

Diesel consumption for the irrigation of conventional orchards and citrus groves has the highest values of CO_2 emissions (**8.1 ktons** in 2010, **7.9 ktons** in 2011, **7.3 ktons** in 2015 and **5.4 ktons** in 2020), while CO_2 emissions for the irrigation of organic orchards and citrus groves, conventional horticulture in field, greenhouse horticulture and organic horticulture in field are the lowest (Figure 3.29).

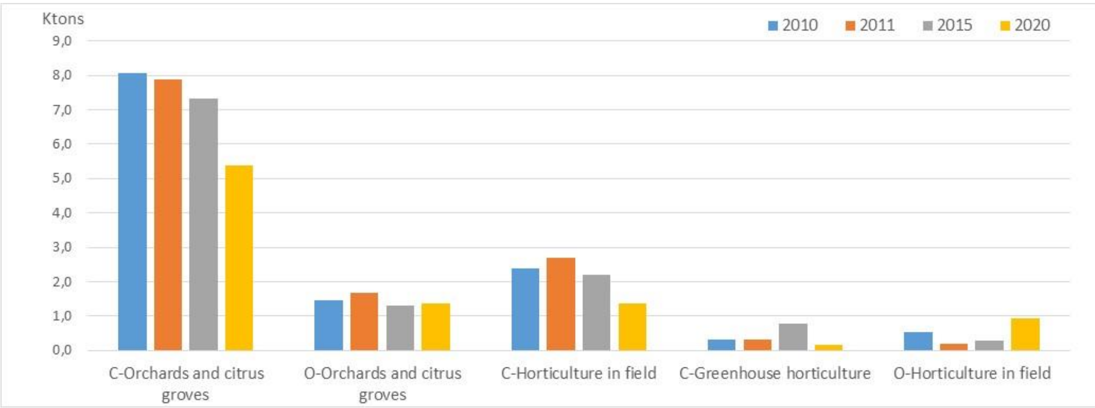

Figure 3.29 CO_2 emissions by irrigation (ktons) – 2010, 2011, 2015 and 2020. Legend: C – Conventional, O- organic.

Regarding CH_4 emissions, enteric fermentation provides the highest contribution (**86%** in 2010, **85%** in 2011 and 2015, **84%** in 2020), followed by manure management (**14%** in 2010 and 2011, **15%** in 2015 and 2020). The contribution of CH_4 emissions from diesel consumption for crop production, livestock and irrigation is negligible.

CH_4 emissions from cattle enteric fermentation (Figure 3.30) are the highest showing an increasing trend (**6.3 ktons** in 2010, **6.2 ktons** in 2011, **6.9 ktons** in 2015 and **7.3 ktons** in 2020). On the other hand, CH_4 emissions from goats and sheep enteric fermentation have a decreasing trend from 2010 to 2020. In particular, CH_4 emissions from goats enteric fermentation are **0.52 ktons** in 2010, **0.51 ktons** in 2011**, 0.34 ktons** in 2015 and **0.31 ktons** in 2020, while the ones from sheep enteric fermentation are **2.68 ktons** in 2010, **2.68 ktons** in 2011**, 2.18 ktons** in 2015 and **1.77 ktons** in 2020. CH_4 emissions from swine enteric fermentation are even lower: **0.11 ktons** in 2010 and 2011, **0.12 ktons** in 2015 and 2020.

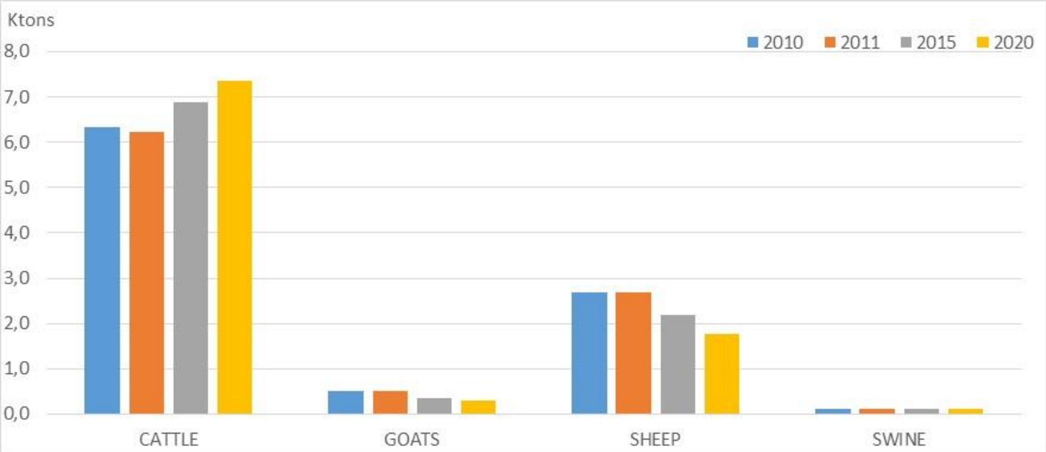

Figure 3.30 CH4 emissions from enteric fermentation (ktons) – 2010, 2011, 2015 and 2020.

Cattle show the highest values of CH_4 emissions also from manure management (**0.9 ktons** in 2010, **0.9 ktons** in 2011, **1 ktons** in 2015 and **1.1 ktons** in 2020). CH_4 emissions from swine manure management are **0.59 ktons** in 2010, **0.6 ktons** in 2011, **0.63 ktons** in 2015 and **0.62 ktons** in 2020. Goats and sheep from manure management record lower CH_4 emissions, being respectively **0.02 ktons** in 2010, **0.02 ktons** in 2011, **0.01 ktons** in 2015, **0.01 ktons** in 2020 and **0.08 ktons** in 2010, **0.08 ktons** in 2011, **0.06 ktons** in 2015, **0.05 ktons** in 2020 (Figure 3.31).

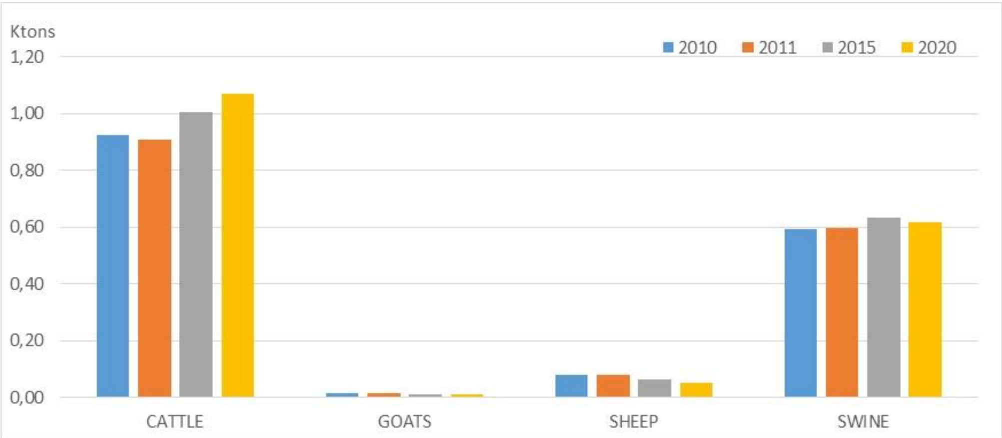

Figure 3.31 CH_4 emissions from manure management (ktons) – 2010, 2011, 2015 and 2020.

In the period 2010-2020 the greatest contribution to N_2O emissions comes from nitrogen fertilizers (between **76%** and **77%**), that from manure management is between **16%** and **18%**, while N_2O emissions from combustion of energy are between **6%** and **7%**.

Regarding the distribution by crop of N_2O emissions due to nitrogen fertilizers (Figure 3.32), conventional cereals show the highest values (**0.09 ktons** in 2010, **0.10 ktons** in 2011, **0.12 ktons** in 2015 and **0.09 ktons** in 2020) followed by conventional permanent grassland and pasture (**0.04 ktons** in 2010, **0.05 ktons** in 2011, **0.05 ktons** in 2015 and **0.05 ktons** in 2020).

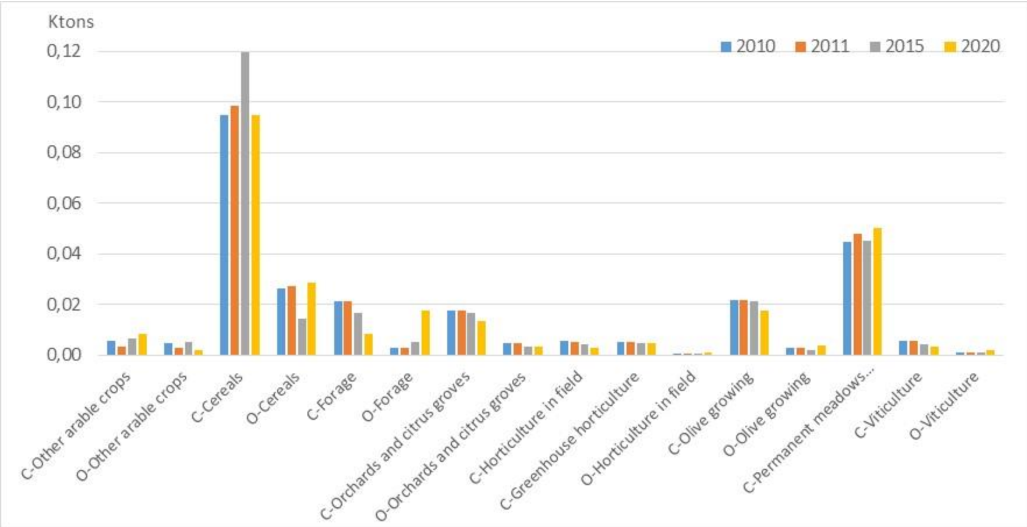

Figure 3.32 N2O emissions from nitrogen fertilzers (ktons) – 2010, 2011, 2015 and 2020. Legend: C-Conventional, O –organic.

As is the case for CH_4 emissions from manure management, cattle produce the highest values of N_2O emissions from manure management as shown in figure 3.37 (**0.046 ktons** in 2010, **0.045 ktons** in 2011, **0.05 ktons** in 2015 and **0.053 ktons** in 2020) followed by N_2O emissions from swine manure management (**0.007 ktons** in 2010, 2011, 2015 and 2020).

Similar to CH_4 emissions, the highest N_2O emissions from manure management are recorded for cattle (**0.046 ktons** in 2010, **0.045 ktons** in 2011, **0.05 ktons** in 2015 and **0.053 ktons** in 2020) followed by those of swine (**0.007 ktons** in 2010, 2011, 2015 and 2020).

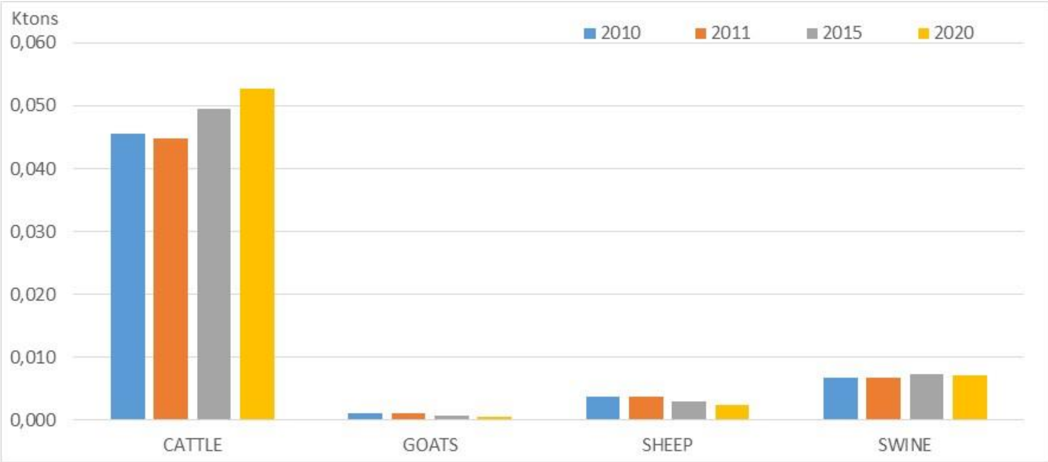

Figure3.33 N_2O emissions from manure management (ktons) – 2010, 2011, 2015 and 2020.

N_2O emissions from energy combustion represent a minor contribution (Figure 3.34). N_2O emissions from diesel consumption for crop production are **0.019 ktons** in 2010, **0,019 ktons** in 2011, **0.018 ktons** in 2015 and **0.018 ktons** in 2020. N_2O emissions from energy combustion for irrigation and for livestock fluctuate between **0.002 ktons** and **0.003 ktons**.

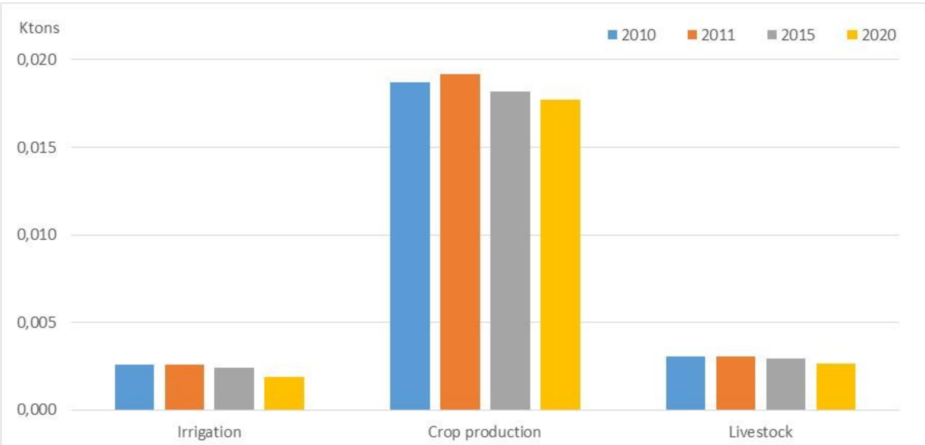

Figure 3.34 N_2O emissions from energy consumptions (ktons) – 2010, 2011, 2015 and 2020.

References Chapter III

Alonso, A. M., Guzmán, G. J. (2010). Comparison of the efficiency and use of energy in organic and conventional farming in Spanish agricultural systems. *Journal of sustainable Agriculture*, 34(3): 312-338.

Banca d'Italia (2020). Annual Report on Basilicata Region economy. Available online: https://www.bancaditalia.it/pubblicazioni/economie-regionali/2020/2020-0017/2017-754 basilicata.pdf (accessed on 6 May 2022).

CNR (2015) ll deserto avanza. Anche in Italia. National Research Council of Italy press release - CNR 730 67/2015. Available online: https://www.cnr.it/it/comunicato-stampa/6272/il-deserto-731 avanza-anche-in-italia (accessed on 15 May 2020).

Coluzzi, R., D'Emilio, M., Imbrenda, V., Giorgio, G. A., Lanfredi, M., Macchiato, M. Telesca, V. (2019) Investigating climate variability and long-term vegetation activity across heterogeneous Basilicata agroecosystems. *Geomatics, Natural Hazards and Risk*, 10(1):. 168-180. DOI 10.1080/19475705.2018.1513872.

Cozzi, M., Di Napoli, F., Viccaro, M., Romano, S. (2013). Use of forest residues for building forest biomass supply chains: technical and economic analysis of the production process. *Forests*, 4(4): 1121-1140.

CREA- Consiglio per la ricerca in agricoltura e l'analisi dell'economia agraria. Report Annuale 2016. Tabelle relative ai fabbisogni delle principali specie animali di interesse zootecnico. https://polaris.crea.gov.it/psr_2014_2020/Regioni/UMBRIA/ANNUALITA2016/MIS.%204_2015/SOTTOMIS.%204.1/OPERAZIONE%204.1.1/UMB_M4.1.1_2017_All_A3_Tab_Produz_Media_Colture_Foraggere.pdf.

CRPA-Centro Ricerche Produzioni Animali Reggio Emilia (2005), Dossier "L'acqua di bevanda negli allevamenti". Available online: Http://www.crpa.it/media/documents/crpa_www/Settori/Edilizia/Download/Archivio-23/acqua.pdf.

CReNBA- Centro di Referenza Nazionale per il Benessere Animale (2020), Valutazione del benessere animale nell'allevamento degli ovini e dei caprini.

Dal Ferro, N., Zanin, G., Borin, M. (2017). Crop yield and energy use in organic and conventional farming: A case study in north-east Italy. *European Journal of Agronomy*, 86: 37-47.

De Pascale, S., Maggio, A., Barbieri, G. (2008). La sostenibilità delle colture protette in ambiente mediterraneo: limiti e prospettive. *Italus Hortus*, 13(3): 33-48.

Eurostat (2020). Available online: https://ec.europa.eu/eurostat/statistics-726 explained/index.php (accessed on 10 April 2022).

Eurostat. (2021, settembre). Agri-environmental indicator - soil erosion. Tratto da https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_soil_erosion#Analysis_at_EU_and_country_level

GSE- Energy Service System Operator (2019). Annual Report. Available online: https://www.gse.it/documenti_site/Documenti%20GSE/Rapporti%20delle%20attivit%C3%763 A0/RA2019.pdf (accessed on 5 April 2022).

IEA (2016) Energy Technology Systems Analysis Programme. Documentation for the TIMES model: 686 PART I. International Energy Agency. Available online: https://iea-687 etsap.org/docs/Documentation_for_the_TIMES_Model-Part-I_July-2016.pdf (accessed on 20 May 2022).

MISE - Ministry of Economic Development (2020). Annual production of hydrocarbons. Available online: https://unmig.mise.gov.it/images/dati/produzione-2020.pdf (accessed on 13 April 2022).

Pimentel, D., Burgess, M. (2014). An environmental, energetic and economic comparison of organic and conventional farming systems. In Integrated Pest Management (pp. 141-166). Springer, Dordrecht.

Regione Basilicata (2022). Basilicata Region soil and climate map. Available online: http://www.basilicatanet.it/suoli/clima.htm (accessed on 29 May 2022).

RDP - Rural Development Program (2015). Basilicata Region Department of Agriculture and Forestry. Available online: https://agricoltura.regione.basilicata.it/programma-di-sviluppo-757 rurale-2014-2020/ (accessed on 15 May 2022).

Salvati, L., De Angelis, A., Bajocco, S., Ferrara, A., Barone, P. M. (2013) Desertification risk, long-term land-use changes and environmental resilience: a case study in Basilicata, Italy.
Scottish 748 Geographical Journal, 129 (2):85-99. DOI 10.1080/14702541.2013.781209.

Statuto, D., Frederiksen, P., Picuno, P. (2019). Valorization of agricultural by-products within the "Energyscapes": Renewable energy as driving force in modeling rural landscape. *Natural Resources Research*, 28(1): 111-124.

Viccaro, M., Rocchi, B., Cozzi, M., Romano, S. (2018) SAM multipliers and subsystems: structural analysis of the Basilicata's agri-food sector. *Bio-based and Applied Economics*, 7(1): 751 19-38. DOI 10.13128/BAE-2404.

Chapter IV *The Scenarios*

4.1 The IPCC climate change scenarios

The Intergovernmental Panel on Climate Change (IPCC), a scientific body established by the World Meteorological Society and the United Nations Environment Program in 1988, is aimed "to provide the world with a clear scientific view on the current state of knowledge in climate change and its potential environmental and socio-economic impacts" by identifying the key issues and areas on which further research is needed.

The IPCC climate assessment reports published every five to seven years with contributions from experts from around the world have high political relevance and summarize the latest scientific findings on impacts and potential responses to climate change and provide guidelines for further studies.

The Sixth Assessment Report (AR6), the latest issue of the IPCC, includes contributions of the three Working Groups: Working Group I (Climate Change 2021: the Physical Science Basis issued on August 2021), Working Group II (Climate Change 2022:Impacts, Adaptation and Vulnerability – issued on February 2022), Working Group III (Climate Change 2022: Mitigation of Climate Change – issued on April 2022) and a Synthesis Report that complements the reports of the three Working Group and the threespecial reports prepared during the AR6 evaluation cycle by the three cross-Working Group Special Reports, namely: Special Report on Global Warming of 1.5ºC (SR15, October 2018), Special Report on Climate Change and Land (SRCCL, August 2019) andthe Special report on the ocean and cryosphere in a changing climate (SROCC, September 2019). The methodologies were also updated with the 2019 Refinement to the 2006 Guidelines on National Greenhouse Gas Inventories, issued in May 2019.

The simulations of future climate evolution conducted by the various research groups required common references so that projections could be comparable with each other. For this purpose, RCPs (Representative concentration Pathways) have been used as a reference, each of which represents a possible path characterized by the concentration of GHG in the atmosphere until 2100, which in turn corresponds to a specific trend in anthropogenic emissions.

The RCPs analysed in the last IPCC Report are reported in Table 4.1, distinting by the radiative forcing in 2100, compared to pre-industrial times. Radiative forcing (in watts per square meter) measures the combined effect of greenhouse gas emissions and other factors (such as atmospheric aerosol levels) on climate warming. Each scenario includes an emissions path represented by the radiative forcing achieved by the end of this century, ranging from the best case of 1.9 watts per square meter to the worst case, catastrophic, of 8.5 watts per square meter.

Moreover, since the Fifth Assessment Report, shared socio-economic pathways (SSPs) were introduced to integrate RCP with socio-economic components for adaptation and mitigation. SSPs are based on five narratives, which describe socioeconomic futures characterized by sustainable development (SSP1), regional rivalry (SSP3), inequality (SSP4), fossil fuel-based development (SSP5), and an intermediate narrative between those described (SSP2). The combination of SSP-based socioeconomic scenarios and RCP-based climate projections provides an integrative framework for climate impact and policy analysis. Table 4.1 shows the main features of the RCPs pathways.

Table 4.1 IPCC scenarios main features.

IPCC scenarios	Radiative forcing values	Global warming by 2100	CO_2 emissions / GHG emissions
RCP 1.9	1.9 W/m^2	below 1.5 °C (Paris Agreementgoal)	emissions declining to net zero around or after 2050, followed by varying levels of net negativeCO_2 emissions
RCP 2.6	2.6 W/m^2	below 2 °C	CO_2 emissions start declining by 2020 and goto zero by 2100
RCP 3.4	3.4 W/m^2	2.0–2.4 °C	CO_2 emissions start declining by 2045 to reachroughly half of the levels of 2050 by 2100
RCP 4.5	4.5 W/m^2	2.0–3.0 °C	Emissions peak around 2040, then decline
RCP 6	6 W/m^2	3.3 °C	Emissions peak around 2080, then decline
RCP 7	7 W/m^2	3.5 °C	Baseline outcome
RCP 8.5	8.5 W/m^2	4.3 °C	Emissions continue to rise throughout the 21stcentury

To refer to future scenarios, AR6 also uses the Global Warming Level (GWL) concept defined as the increase in the global average air temperature near the surface compared to the pre-industrial period. In particular, GWLs are used to describe the settings of climatic parameters, socio-economic variables and ecosystems resulting from climate change, typically using values of 1,5 °C, 2 °C, 3 °C or 4° C. As greenhouse gas concentrations increase, GWL values increase and with them climate alterations on a regional and global scale, their impacts and consequent risks.

The vulnerability of agricultural production has been identified as one of the main risks for the future. In particular, due to a combination of heatwaves and droughts, substantial losses in agricultural production are expected in the 21st century for most areas of Europe not compensated by the expected gains for Northern Europe. In the last decades, crop losses due to drought and heat have tripled over the past five decades (Brás, 2021), underlining the importance of assessing multiple stresses.

In general, the observed impacts affect negatively almost all crop categories, although some exceptions of positive impacts have been reported (Alae-Carew, 2020). In recent years, in southern Europe, global warming has negatively affected the yields of nearly all major crops, leading to recent crop stagnation (Moore, 2015; Agnolucci, 2020; Brás, 2021).

Another aspect highlighted by the AR6 is that the high concentrations of CO_2 could have a fertilizing effect that stimulates the rates of photosynthesis and the accumulation of biomass, improving also the efficiency of water use of various crop species (Toreti, 2020), although this does not always translate into higher yields and better product quality (Kimball, 2016; Zhu, 2018).

Furthermore, in some cases the positive effects of CO_2 increase can be significantly reduced by other climate stressors such as rising temperatures (Purcell, 2018; Wang, 2018).

The differences are also related to the level of temperature and heating currently recorded in the different areas. The predicted effects of climate change are positive when current average annual temperatures are below 10 °C, but become negative for values above about 15 °C (Jägermeyr, 2021).

A complete overview of the phenomena taking place in the Mediterranean area is reported in chapter 4 of the WGII report, with a detail on the impacts of climate change on the agricultural sector. Over time, agricultural yields will decline mainly due to higher temperatures affecting crop phenology and shortening the growing season of crops.

Furthermore, since additional irrigation will be required for most crops, it is estimated that irrigation needs could increase by 25% in the north-central Mediterranean (Fader, 2016). In particular, an increase in temperature of + 1 °C would result in a reduction in precipitation of -5% and in a more extreme scenario characterized by an increase in temperature of + 6 °C a reduction of up to -30% (Dettori, 2017), while the use of supplemental irrigation for winter wheat may become more common in the northern Mediterranean (Ruiz-Ramos, 2018).

Iocola et al (2017), through simulation models, supported by datasets from long-term experiments on case studies in Italy, evaluated the impacts of climate change on corn and durum wheat production in two different climate scenarios (RCP4.5 and RCP8.5) for the period 2021-2050.

The predicted effects on crops are similar for both scenarios with a slightly greater impact in the second. In terms of yields, an average reduction of 23% is expected for maize and 18% for durum wheat.

Olive growing is another very important sector in Southern Europe, which includes 80% of the world olive area and produces around 95% of the world olive oil supply. Fraga et al (2020) estimated the impact of climate change on olive groves in the period 2041-2070. The results show an extension of the duration of the growing season within RCP4.5 and RCP8.5 and a decrease in yields in some inland areas of southern Italy up to -15%. The predicted effects on crops are similar for both scenarios with a slightly greater impact in the second.

Georgopoulou (2017) pointed out that summer crops, including tomatoes, can also be strongly influenced by climate change. For southern Italy, considering the period 2030-2059 and a climatic scenario characterized by + 2 °C, the positive fertilizing effect of the increase in CO_2 concentration will not be sufficient to overcome the negative effects caused by the increase in temperature and, in particular, from the reduction of rainfall, with a negative effect on the tomato yield of about -10%.

As far as viticulture is concerned, changes in climatic conditions should affect yields, as well as the quality of wine, by modifying the percentage between sugar and acids.

Lionello et al. (2014) estimated that, for southern Italy, an increase in temperature above + 2 °C could cause an estimated decrease in wine production (hl) of about 20-26% in the period 2021-2050.

Valverde (2015) focusing the research in southern Portugal, a Mediterranean region with semi-arid and sub-humid conditions, shows that considering the A2, A1B and B1 emissions scenarios and an increase of 2 °C of the temperatures, in the future periode (2041-2070) several crops could register a losses of yields. Namely, grain legumes – 2.5%; winter fodder -7.89% and pastures -10%.

The information extracted from the AR6 of the IPPC will be suitably harmonized with respect to the categories and period analyzed by the model to obtain performance parameters, relating to the loss of yields, to be used in the scenario analysis. The details will be described in the paragraph dedicated to climate scenarios.

4.2 The EU Common Agricultural policy scenarios

Since the 1990s, the Common Agricultural Policy (CAP) has pursued a path of progressive strengthening of the commitment towards environmental sustainability. The post-2020 reform represents the last stage of the progressive greening process of the CAP (De Castro, 2020).

The slowdown in negotiations on the CAP, which ended two years later than thescheduled date, led to the postponement of its start from 2021 to 2023. This delay, in addition to the difficulties in finding an agreement on the financial resources and contentsof the reform, is partly attributable to the spread of the COVID-19 pandemic. In particular,the COVID-19 pandemic has highlighted the resilience of the agricultural sector but alsoits fragility, giving greater visibility and incisiveness to the EU strategy.

The European Green Deal, taking note of the changes taking place and of the international commitments signed by the European Union in the context of COP21, defined the overall strategy with long-term objectives and guidelines to be undertaken in operational terms (EU, 2019).

In fact, the Farm to Fork Strategy (EU, 2020b) and the European Biodiversity Strategy for 2030 (EU, 2020a), published subsequently, specify the actions of the Green Deal with reference to agricultural and rural development policies.

In particular, the Farm to Fork strategy outlines a "new decision making level" on the basis of which agricultural policy emerges from its condition of isolation from other common European policies and is appropriately framed in an overall system of long-term objectives relating to health, food safety and the environment.

As a result, the European Green Deal and the Farm to Fork Strategy consolidate a multilevel Common Agricultural Policy after 2020.

In operational terms, the Farm to Fork Strategy is developed around six macro-objectives, which concern the sustainability of food production, safety in food supply (the so-called Food Security), sustainability in the phases of the food supply chains following the agricultural one (distribution, sales, catering, etc.), the promotion of sustainable food consumption, the reduction of food losses and waste and the fight against fraud in the food supply chains. Therefore, it is a very broad strategy that crosses various European policies and funds, designed to address various challenges that require a systemic and complex approach expressed in some ambitious objectives to be achieved by 2030, including:

- reduce the use of chemical pesticides by 50%;
- reduce nutrient losses by at least 50% ensuring that there is no deterioration in soil fertility; this implies a reduction in the use of fertilizers by at least 20% by 2030;
- allocate at least 25% of the agricultural area to organic farming by 2030.

Therefore, the Farm to Fork Strategy actions involve the development of incentives for producers (i.e. new support to organic farming) or seek to improve the farming situation (i.e. new competition rules enhancing farmers' bargaining power). Certainly, these two components (new constraints and new incentives) show how, the current CAP, is far from these new approaches.

On this basis, the European Commission must use the Strategy policy actions to refresh the CAP tools as well as to strengthen the agricultural contribution to achieve a fair, healthy and environmentally friendly EU agri-food chain (Massot, 2020).

The new CAP delivery model and their National Strategic Plans theoretically offer Member States the possibility of developing tailormade and more result-oriented agricultural interventions in order to achieve simultaneously the Green Deal and Farm to Fork political priorities and the national targets.

The current dramatic political scenario threatens the implementation of the CAP and the F2F, as the war in Ukraine represents a serious danger for the stability of the European agricultural system. In fact, Russia and Ukraine account for over 30% of world trade in wheat and barley, 17% for maize and over 50% for sunflower oil.

According to CREA (2022), because of the current geopolitical crisis, the average increase in production costs for Italian companies will be around 54%, differentiated by production sector, with relevant effects on the economic sustainability of farms. In particular, the most significant increase in expenditure will be recorded for fertilizers, with an estimated annual increase in the price of + 170%, and for agricultural diesel, both as fuel for driving machines and for thermal and electric energy production, which will increase by 129%. A moderate price increase is instead estimated for pesticide products (about 15%).

Discussions are ongoing in Brussels on how to help farmers cope with rising fuel and fertilizer prices and how to increase grain production and stocks, possibly deferring the implementation of environmental regulations. In fact, a temporary derogation from the reinforced conditionality of the European Common Agricultural Policy is envisaged, suspending compliance with some requirements for receiving payments, including the constraint of having at least 3% of the land suitable for biodiversity. The derogation, on the other hand, would provide an incentive to allocate the land to be kept uncultivated for biofuels growing, which are essential for the European supply chain.

4.3 Setup of the Times Basilicata Land-WEF scenarios

The scenario analysis performed with the TIMES Basilicata Land WEF model aims to assess the medium to long-term development of the agricultural system taking into account different evolutionary conditions.

Taking into account the political and environmental framework described in the previous paragraphs, the scenario analysis pursued two main objectives: assessing the effect of climate change and assessing the consequences of EU policies and strategy in terms of resource availability for the agricultural sector and redistribution of agricultural production.

The operating characterization of the scenarios implies the identification of exogenous constraints and, consequently, of the variables to be transposed into model parameters to represent the various evolutionary paths of the agricultural system that are compared to a "status quo" path.

In the following sections, the scenario hypotheses are discussed in details.

4.3.1 The Reference Scenario: a "Business as Usual" benchmark

The definition of a baseline for the comparison, the so-called "Business as Usual" scenario is the first essential step of any scenario analysis.

The BaU scenario of the TIMES Basilicata Land WEF model describes the initial framework and the tendential development of the agricultural system of the Basilicata region taking into account its current state (availability of resources and technologies, land use, policies in place, etc.).

As concern the main assumptions, the final demand is considered constant over the entire time horizon (2020-2060), both for agricultural and forestry land use and for number of livestock heads. In 2060 the variation in land use of each crop production is between -10% and + 10% of the values assumed in 2020. For the agricultural activities, also the diesel consumption, the input of fertilizers (nitrogen, phosphate, and potassium) and active substances for crop protection per unit of main product are considered constant over the entire time horizon. The same assumptions are considered for electricity, natural gas and diesel consumption per head unit of livestock.

Through the Reference scenario it is possible to analyze how land use for agricultural production varies over the time horizon among the processes (both conventional and organic) considered by the model.

In addition, it allows to analyze the consumption trends for fertilizers, active substancesin plant protection products, fuel and water (these last for both agricultural and livestock processes as well as the production of reusable waste for energy purpose, both for agricultural and livestock processes).

Finally, to analyze, over time, what is the contribution of each process to environmental deterioration in terms of production of CO_2, N_2O and CH_4 emissions.

4.3.2 The climate scenarios

The IPCC reports identify different climate scenarios and highlight the guiding parameters for examining the effects of climate change.

Taking into account the characteristics of the model, land use and the availability of agricultural resources were chosen as key parameters directly linked to the model variables to define the scenario hypotheses.

In particular, the expected loss of yield, a phenomenon that will characterize the future of southern Europe mainly due to the higher temperatures that affect the phenology of crops and the shortening of the growing season of crops.

The analysis will focus on a single climate scenario, in which a temperature increase of 2 degrees is expected. This choice is linked to the fact that the results of the decrease in yields recorded for many crops are similar considering the two key scans, RCP 4.5 and RCP 8.5, used by the IPCC to model and evaluate different climatic futures. Table 4.2 shows the main characteristics of the climate scenario (+ 2 °C) analyzed with the TIMES Basilicata Land WEF.

Table 4.2 TIMES Basilicata Land-WEF climate scenarios.

Agricultural Process	**Percentage yield crops reduction**	**Period**
Cereal	-20,5%	2021-2050
Other arable crops	-2,5%	2041-2070
Forage	-8%	2041-2070
Orchads and citrus groves	-15%	2041-2070
Horticulture	-10%	2030-2059
Olive growing	-15%	2041-2070
Viticulture	-23%	2021-2050
Permanent meadows and pastures	-10%	2041-2070

For cereals an average value of reduction is assumed considering the trend of maize and durum wheat.

For horticulture, the value refers to tomatoes and to grain legumes for other arable crops.

For orchards, since there are no studies relating to the main types cultivated in the sample area used for the development of the model (oranges and apricots) and assuming for these similar agronomic characteristics, the value recorded for the olive groves was considered.

For all categories, the reductions were considered similar for both types of cultivation, organic and conventional. Moreover, it is assumed that the energy consumption per hectare, the use of fertilisers per hectare, and the use of substances for the defence of both conventional and organic crops per hectare are equal to the values obtained in the BAU scenario.

4.3.3 The agricultural policy scenarios

The policy scenarios analyse the effects on agricultural system of the CAP and F2F EU policies.

The considered constraints are the following:

- Reduction from 10% to 20% in fertilizer consumption by 2030 compared to 2020 values.
- Reduction of 50% in the use of active substances in plant protection active substances in plant protection products for conventional crops by 2030 compared to 2020 values.
- Minimum share of organic agricultural land equal to 25%.

Three scenarios were defined with reference to fertilisers, to perform a sensitivity analysis aimed at better characterising the response of the agricultural system to different policy boundaries and, in particular, to understand if there are driving targets that can foster the achievement of other limitations (e.g. reduction of fertilisers, share of organic land and CO_2 emission levels). Table 4.3 summarizes the agricultural policy scenarios features.

Table 4.3 Agricultural policy scenarios.

Scenario	Reduction of fertilisers (%) by 2030 face to 2020	Reduction of active substances (%) by 2030 face to 2020	Organic agricultural land
FERT_10	- 10%	n.a.	Unconstrained
FERT_20	- 20%	n.a.	Unconstrained
FERT_20_O25	- 20%	n.a	Minimum share 25%
PEST_50	n.a.	-50%	Minimum share 25%

References Chapter IV

Agnolucci, P., De Lipsis, V., (2020) Long-run trend in agricultural yield and climatic factorsin Europe. *Clim. Change*, 159(3): 385-405, doi:10.1007/s10584-019-02622-3.

Alae-Carew, C. et al., (2020) The impact of environmental changes on the yield and nutritionalquality of fruits, nuts and seeds: a systematic review. *Environ. Res. Lett.*, 15(2), 023002, doi:10.1088/1748-54 9326/ab5cc0.

Brás, T. A., Seixas, J., Carvalhais, N., Jägermeyr, J. (2021) Severity of drought and heatwave crop losses tripled over the last five decades in Europe. *Environ. Res. Lett.*, 16, 065012, doi:10.1088/1748-38 9326/abf004.

CREA, Report "Guerra in Ucraina: gli effetti sui costi e sui risultati economici delle aziende agricole italiane" marzo 2022. https://rica.crea.gov.it/download.php?id=1742

De Castro, P., Miglietta, P. P., Vecchio, Y. (2020) The Common Agricultural Policy2021-2027: a new history for European agriculture. *Italian Review of Agricultural Economics* 75(3): 5-12. DOI: 10.13128/rea-12703.

Dettori, M., Cesaraccio, C., Duce, P. (2017) Simulation of climate change impacts on production and phenology of durum wheat in Mediterranean environments using CERES-Wheat model. *Field Crops Research*, 206: 43-53, doi:10.1016/j.fcr.2017.02.013.

EU-COM. (2019). The European Green Deal, COM(2019) 640 Final.

EU (2020a) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions EU Biodiversity Strategy for 2030. COM/2020/380 final.

EU (2020b) Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of Regions A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system. COM/2020/381 final.

Fader, M. et al., (2016) Mediterranean irrigation under climate change: more efficient irrigationneeded to compensate for increases in irrigation water requirements. *Hydrology and Earth System Sciences*, 20(2): 953-973, doi:10.5194/hess-20-953-2016.

Fraga, H., García de Cortázar Atauri, I., 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, doi:10.1111/gcb.13382.

García Azcárate T., Folkeson C. (2020). The new delivery model of the CAP: Some relevant issues. Economía Agraria y Recursos Naturales. *Agricultural and Resource Economics*, 20(1): 149-167. DOI: 10.7201/earn.2020.01.07

Georgopoulou, E. et al., (2017) Climate change impacts and adaptation options for the Greek agriculture in 2021–2050: A monetary assessment. *Climate Risk Management*, 16: 164-182, doi:10.1016/j.crm.2017.02.002.

Iocola, I. et al., (2017) Can conservation tillage mitigate climate change impacts in Mediterranean cereal systems? A soil organic carbon assessment using long term experiments. *European Journal of Agronomy*, 90: 96-107, doi:10.1016/j.eja.2017.07.011.

IPCC (2018). 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.

IPCC (2019a). Special Report on climate change, desertification, land degradation, sustainable land management, food security, and greenhouse gas fluxes in terrestrial ecosystems.

IPCC (2019b). Special Report on the Ocean and Cryosphere in a Changing Climate.

Jägermeyr, J. et al., (2021) Climate change signal in global agriculture emerges earlier in newgeneration of climate and crop models". *Nat. Food*, 2: 873-885, doi:10.21203/rs.3.rs- 101657/v1.

Lionello, P. et al., 2014: The climate of the Mediterranean region: research progress and climate change impacts. *Regional Environmental Change*, 14(5): 1679-1684, doi:10.1007/s10113-014-0666-0.

Massot Marti, A., (2020) Research for AGRI Committee – [The Farm to Fork Strategy implications for agriculture and the CAP], European Parliament, Policy Department for Structural and Cohesion Policies, Brussels.

Purcell, C. et al., (2018) Increasing stomatal conductance in response to rising atmospheric CO_2. *Ann. Bot.*, 121(6): 1137-1149, doi:10.1093/aob/mcx208.

Ruiz-Ramos, M. et al., (2018) Adaptation response surfaces for managing wheat under perturbed climate and CO_2 in a Mediterranean environment. *Agricultural Systems*, 159: 260-274, doi:10.1016/j.agsy.2017.01.009.

Toreti, A. et al., 2020: Narrowing uncertainties in the effects of elevated CO_2 on crops. *Nat. Food*, 1(12), 775-782, doi:10.1038/s43016-020-00195-4.

Valverde, P., de Carvalho, M., Serralheiro, R., Maia, R., Ramos, V., Oliveira, B. (2015). Climate change impacts on rainfed agriculture in the Guadiana river basin (Portugal). *Agricultural Water Management*, 150: 35-45.

Wang, W. L. et al., (2018) Elevated CO_2 cannot compensate for japonica grain yield losses under increasing air temperature because of the decrease in spikelet density. Eur J Agron, 99: 21-29, 10 doi:10.1016/j.eja.2018.06.005.

Zhu, P. et al., (2018) The important but weakening maize yield benefit of grain fillingprolongation in the US Midwest. *Glob Chang Biol*, 24(10): 4718-4730, doi:10.1111/gcb.14356.

Chapter V *The scenario analysis*

5.1 The Reference Business as Usual scenario

The Reference Business as Usual (BAU) scenario investigates the optimised evolution of the agricultural system in a *status quo* situation providing the benchmark for the subsequent scenario analysis.

The results highlight that land use for agricultural production varies over the time horizon and a larger use of land for permanent meadows and pastures and for olive growing with both conventional and organic techniques is observed.

Conventional permanent meadows and pastures increase **10%,** from **116'325 ha** in 2020 to **127'958 ha** in 2060. A **10%** increase is also observed for organic permanent meadows and pastures (from **19'264 ha** in 2020 to **21'190 ha** in 2060), conventional olive growing (from **22'142 ha** in 2020 to **24'356 ha** in 2060) and organic olive growing (from **5'468 ha** in 2020 to **6'015 ha** in 2060). On the other hand, there is a 5% increase in land use for organic forage, which goes from **26'297 ha** in 2020 to **27'627 ha** in 2060. For the remaining crop productions, a **10%** reduction in land use is observed in 2060 compared to 2020, with the exception of organic cereals production (economically less competitive), which decreases by **3%**.

Table 5.1 shows land use for agricultural production over the time horizon for both conventional and organic crops.

Table 5.1 Land Use for agricultural production (Hectares by crop).

Unit (ha)	**2010**	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**
Other Arable Crops – Conventional	1150	1843	1751	1738	1725	1711	1698	1685	1672	1659
Other Arable Crops – Organic	543	202	192	190	189	188	186	185	183	182
Cereals - Conventional	139426	121842	115750	114880	114009	113139	112269	111398	110528	109658
Cereals - Organic	19425	37127	36545	36462	36379	36295	36212	36129	36046	35963
Forage - Conventional	29520	13297	12632	12537	12442	12347	12252	12157	12062	11967
Forage - Organic	6423	26297	26962	27057	27152	27247	27342	27437	27532	27627
Orchards And Citrus Groves - Conventional	16318	11920	11324	11239	11154	11069	10983	10898	10813	10728
Orchards And Citrus Groves - Organic	2978	3056	2903	2881	2860	2838	2816	2794	2772	2750
Horticulture In The Field- Conventional	8869	5629	5348	5307	5267	5227	5187	5147	5106	5066
Greenhouse Horticulture - Conventional	1165	711	675	670	665	660	655	650	645	640
Horticulture In The	2025	3838	3646	3619	3591	3564	3536	3509	3482	3454

Field - Organic										
Olive Growing - Conventional	28487	22142	23249	23407	23565	23724	23882	24040	24198	24356
Olive Growing - Organic	2864	5468	5741	5780	5820	5859	5898	5937	5976	6015
Permanent Meadows And Pastures - Conventional	67646	116325	122141	122972	123803	124634	125465	126296	127127	127958
Permanent Meadows And Pastures - Organic	9509	19264	20227	20365	20502	20640	20778	20915	21053	21190
Viticulture - Conventional	4634	1586	1507	1495	1484	1473	1461	1450	1439	1427
Viticulture - Organic	727	930	884	877	870	864	857	850	844	837
Total Hectares	**341708**	**391477**	**391477**	**391477**	**391477**	**391477**	**391477**	**391477**	**391477**	**391477**

Table 5.2 shows the percentage contribution of each agricultural production for each period: it is evident that conventional permanent meadows and pastures replace conventional cereals starting from 2025.

Table 5.2 Percentage of land use (hectares) for agricultural production.

	2010	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**
Other Arable Crops – Conventional	0.3%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
Other Arable Crops –Organic	0.2%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Cereals - Conventional	40.8 %	31.1 %	29.6 %	29.1 %	29.1%	28.7 %	28.2 %	27.8 %	27.3%	26.9%
Cereals - Organic	5.7%	9.5%	9.3%	9.3%	9.3%	9.3%	9.2%	9.2%	9.1%	9.1%
Forage - Conventional	8.6%	3.4%	3.2%	3.2%	3.2%	3.1%	3.1%	3.0%	3.0%	2.9%
Forage - Organic	1.9%	6.7%	6.9%	6.9%	6.9%	7.0%	7.0%	7.1%	7.1%	7.2%
Orchards and Citrus Groves - Conventional	4.8%	3.0%	2.9%	2.8%	2.8%	2.8%	2.8%	2.7%	2.7%	2.6%
Orchards And Citrus Groves - Organic	0.9%	0.8%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%
Horticulture In the Field- Conventional	2.6%	1.4%	1.4%	1.3%	1.3%	1.3%	1.3%	1.3%	1.3%	1.2%
Greenhouse Horticulture - Conventional	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Horticulture In the Field - Organic	0.6%	1.0%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.9%	0.8%
Olive Growing - Conventional	8.3%	5.7%	5.9%	6.0%	6.0%	6.1%	6.2%	6.3%	6.3%	6.4%
Olive Growing - Organic	0.8%	1.4%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.6%	1.6%
Permanent Meadowsand Pastures - Conventional	19.8 %	29.7 %	31.2 %	31.6 %	31.6%	32.0 %	32.5 %	32.9 %	33.3%	33.7%
Permanent Meadows and Pastures - Organic	2.8%	4.9%	5.2%	5.2%	5.2%	5.3%	5.4%	5.4%	5.5%	5.6%
Viticulture - Conventional	1.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
Viticulture - Organic	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%

Land use share between conventional and organic does not show substantial variations as the hectares used for organic production are around **25%** over the entire time horizon.

As obvious, land use variations reflect on agricultural production over the time horizon as reported in Table 5.3.

Table 5.3 Agricultural production (tons).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Other Arable Crops – Conventional	2463	3745	3557	3531	3504	3477	3450	3424	3397	3370
Other Arable Crops – Organic	891	410	390	387	384	381	378	375	372	369
Cereals - Conventional	328552	328904	312459	310110	307760	305411	303062	300712	298363	296014
Cereals - Organic	91037	100222	98650	98426	98202	97977	97753	97528	97304	97079
Forage - Conventional	393901	152667	145033	143943	142852	141762	140671	139581	138490	137400
Forage - Organic	45999	301923	309557	310647	311738	312828	313919	315009	316100	317190
Orchards And Citrus Groves - Conventional	246983	189322	179856	178504	177152	175799	174447	173095	171742	170390
Orchards And Citrus Groves -Organic	66201	48538	46111	45764	45417	45071	44724	44377	44031	43684
Horticulture In the Field- Conventional	328529	179349	170382	169101	167820	166538	165257	163976	162695	161414
Greenhouse Horticulture - Conventional	22352	21032	19980	19830	19680	19530	19379	19229	19079	18929
Horticulture In the Field - Organic	58549	122285	116171	115297	114424	113550	112677	111803	110930	110056
Olive Growing - Conventional	37723	30364	31883	32100	32316	32533	32750	32967	33184	33401
Olive Growing - Organic	5559	7499	7873	7927	7981	8034	8088	8141	8195	8248
Permanent Meadows andPastures - Conventional	155922	174743	183480	184728	185976	187224	188473	189721	190969	192217
Permanent Meadows and Pastures - Organic	6278	28938	30385	30592	30799	31005	31212	31419	31625	31832
Viticulture - Conventional	41760	25436	24164	23982	23800	23619	23437	23255	23074	22892
Viticulture -Organic	7025	14915	14169	14063	13956	13850	13743	13636	13530	13423

As for fuel consumption, diesel shows a reduction over the time horizon. Table 5.4 shows diesel oil consumption for the different uses. Total diesel consumption goes from **1.59 PJ** in 2020 to **1.52 PJ** in 2060. This trendis mainly attributable to the decrease in diesel consumption due to several process of cultivation -plowing etc ... (from **1.26 PJ** in 2020 to **1.22 PJ** in 2060) and, to a lesser extent, to that for irrigation (from **0.13 PJ** in 2020 to **0.12 PJ** in 2060) while the consumption for livestock is constantover the time horizon.

Table 5.4 Year diesel consumption by use (PJ).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Agricultural production	1.34	1.26	1.24	1.24	1.23	1.23	1.23	1.22	1.22	1.22
Livestock	0.22	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
Irrigation	0.18	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0.12
Total	**1.74**	**1.59**	**1.55**	**1.55**	**1.55**	**1.54**	**1.54**	**1.53**	**1.53**	**1.52**

Comparing diesel consumption in 2020 and 2060 (Figure 5.1), it is observed a greater weight of the production of conventional cereals (**36%** in 2020 and **34%** in 2060) compared to all other agricultural productions and negligible percentage changes in the distribution of diesel consumption.

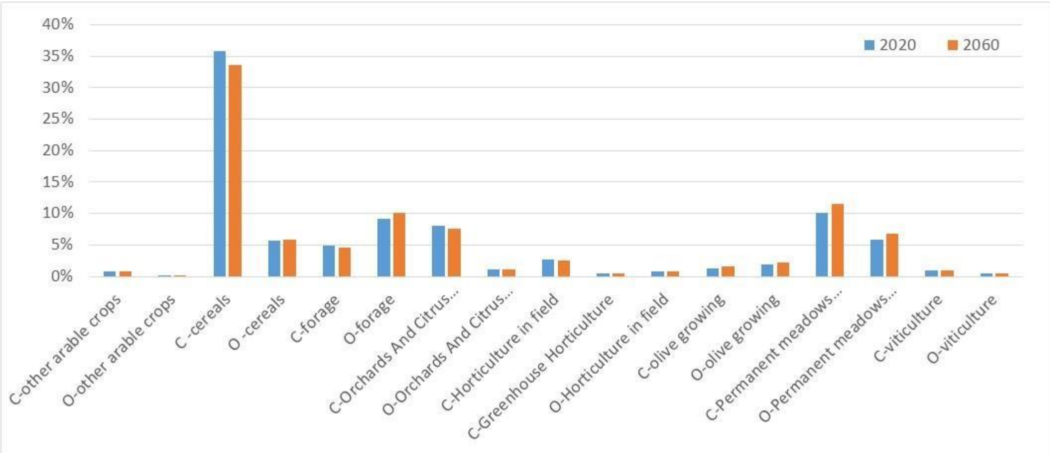

Figure 5.1 Comparison of diesel consumption. Legend: C [Conventional] O [Organic].

The use of fertilizers decreases over the time horizon (Table 5.5). Nitrogen fertilizers decrease by **3%** in 2060 compared to 2020 (going from **16’716 tons** in 2020 to **16’252 tons** in 2060). On the other hand, a **6%** reduction is observed both for phosphate fertilizers (by **934 tons** in 2020 to **881 tons** in 2060) and for potash fertilizers (from **952 tons** in 2020 to **892 tons** in 2060).

Tab. 5.5 Use of fertilizers (tons).

	2010	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**
Nitrogen Fertilizers	16808	16716	16484	16451	16418	16385	16351	16318	16285	16252
Phosphate Fertilizers	1136	934	907	903	900	896	892	888	885	881
Potash Fertilizers	1167	952	922	918	913	909	905	900	896	892

Table 5.6 shows the use of nitrogen fertilizers over the time horizon for each type of agricultural production. In accordance with the trend in agricultural production, the use of nitrogen fertilizers for conventional cereals is reduced by **604 tons** in 2060 compared to 2020, while the highest increases are recorded for conventional permanent meadows and pastures (**+320 tons** in 2060 compared to 2020) and for conventional olive growing (**+112 tons**).

Table 5.6 Use of nitrogen fertilizers by type of agricultural production (tons).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Other Arable Crops – Conventional	353	537	510	506	502	498	495	491	487	483
Other Arable Crops – Organic	284	131	124	123	122	121	121	120	119	118
Cereals - Conventional	6035	6041	5739	5696	5653	5610	5567	5524	5480	5437
Cereals - Organic	1661	1829	1800	1796	1792	1788	1784	1780	1776	1772
Forage - Conventional	1363	528	502	498	494	490	487	483	479	475
Forage - Organic	171	1120	1149	1153	1157	1161	1165	1169	1173	1177
Orchards and Citrus Groves - Conventional	1112	852	809	803	797	791	785	779	773	767
Orchards And Citrus Groves - Organic	296	217	206	205	203	201	200	198	197	195
Horticulture In The Field- Conventional	340	185	176	175	174	172	171	170	168	167
Greenhouse Horticulture - Conventional	309	291	276	274	272	270	268	266	264	262
Horticulture In The Field - Organic	32	67	64	63	63	62	62	61	61	61
Olive Growing - Conventional	1392	1120	1176	1184	1192	1200	1208	1216	1224	1232
Olive Growing - Organic	183	247	259	261	263	265	266	268	270	272
Permanent Meadows and Pastures - Conventional	2856	3201	3361	3384	3407	3430	3453	3476	3498	3521
Viticulture - Conventional	362	220	209	208	206	204	203	201	200	198
Viticulture - Organic	60	128	122	121	120	119	118	117	116	115
Total use of nitrogen fertilisers	**16808**	**16716**	**16484**	**16451**	**16418**	**16384**	**16351**	**16318**	**16285**	**16252**

Phosphate fertilizers show the greatest decline for conventional orchards and citrus groves (**-23 tons** in 2060 compared to 2020) and for conventional cereals (**-16 tons**) (Table5.7). Instead, an increase is observed for conventional olive growing (**+18 tons** in 2060 compared to 2020).

Table 5.7 Use of Phosphate fertilisers by type of agricultural production (tons).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Other Arable Crops – Conventional	4	6	5	5	5	5	5	5	5	5
Cereals - Conventional	160	161	153	151	150	149	148	147	146	145
Cereals - Organic	11	12	12	12	12	12	12	12	12	12
Forage - Conventional	39	15	14	14	14	14	14	14	14	13
Orchards And Citrus Groves - Conventional	306	234	223	221	219	218	216	214	213	211
Orchards And Citrus Groves - Organic	114	84	79	79	78	78	77	76	76	75
Horticulture In The Field- Conventional	83	45	43	43	42	42	42	41	41	41
Greenhouse Horticulture - Conventional	87	81	77	77	76	76	75	74	74	73
Horticulture In The Field - Organic	18	37	35	35	35	34	34	34	34	33
Olive Growing - Conventional	223	179	188	190	191	192	193	195	196	197
Olive Growing - Organic	14	19	20	20	20	20	21	21	21	21
Viticulture - Conventional	70	43	40	40	40	40	39	39	39	38
Viticulture - Organic	8	18	17	17	16	16	16	16	16	16
Total use of phosphate fertilizers	**1136**	**933**	**907**	**903**	**899**	**896**	**892**	**888**	**884**	**881**

Conventional orchards and citrus groves recorded the highest decrease in the use of potash fertilizers in 2060 compared to 2020 (**-34 tons**) while organic orchards, organic citrus groves and conventional greenhouse horticulture show a reduction of **11 tons** in the use of potash fertilizers in 2060 compared to 2020 (Table 5.8). In contrast, conventional olive growing has an increase of **15 tons** in 2060 compared to 2020.

Table 5.8 Use of Potash fertilisers by type of agricultural production (tons).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Cereals - Conventional	42	42	40	39	39	39	38	38	38	37
Cereals - Organic	16	18	18	18	18	18	18	18	18	17
Forage - Conventional	12	5	4	4	4	4	4	4	4	4
Orchards And Citrus Groves - Conventional	442	339	322	319	317	314	312	309	307	305
Orchards And Citrus Groves - Organic	156	114	108	107	107	106	105	104	103	103
Horticulture In The Field- Conventional	85	46	44	44	43	43	43	42	42	42
Greenhouse Horticulture - Conventional	118	111	105	105	104	103	102	101	101	100
Horticulture In The Field - Organic	27	57	54	53	53	53	52	52	51	51
Olive Growing - Conventional	184	148	155	156	158	159	160	161	162	163
Olive Growing - Organic	16	21	22	23	23	23	23	23	23	23
Viticulture - Conventional	65	39	37	37	37	37	36	36	36	35
Viticulture - Organic	6	12	12	12	12	11	11	11	11	11
Total use of potash fertilizers	**1167**	**952**	**922**	**917**	**913**	**909**	**905**	**900**	**896**	**892**

The use of active substances in plant protection products shows a decrease over time horizon of **-38.7 tons** (corresponding to **-6%**) in 2060 compared to 2020 for conventional agricultural production and **-1 ton** (corresponding to **-9%)** for organic agricultural productions (Table5.9).

Table 5.9 Use of active substances by crop production (tons).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Active substances of plant protection - conventional products	780.0	612.5	593.1	590.3	587.6	584.8	582.0	579.3	576.5	573.7
Active substances of plant protection – organic products	9.5	11.8	11.2	11.2	11.1	11.0	10.9	10.9	10.8	10.7

Analysing the trend in the use of active substances in plant protection products (Table 5.10), a decrease is evident in 2060 compared to 2020 for orchards and citrus groves (**-22.1 tons**), for greenhouse horticulture (**-10 tons**), and for cereals (**+8.3 tons**). On the contrary, the use of active substances for the protection of conventional olive growing increases by **11.2 tons** in 2060 compared to 2020.

Table 5.10 Use of active substances in plant protection products for conventional crop protection (tons).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Other Arable Crops – Conventional	0.6	0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.8	0.8
Cereals - Conventional	836	83	79	78	77	77	76	76	75	74
Orchards And Citrus Groves - Conventional	288	221	210	208	206	205	203	202	200	199
Orchards And Citrus Groves - Conventional	56,6	31	29	29	29	29	28	28	28	28
Greenhouse Horticulture - Conventional	106	100	95	94	93	93	92	91	90	90
Olive Growing - Organic	139	112	118	119	119	120	121	122	123	123
Permanent Meadows and Pastures - Conventional	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Viticulture - Conventional	107	65	62	61	61	60	60	59	59	58

In the case of organic agricultural production (Table 5.11) the use of active substances in plant protection products shows a reduction of **0.6 tons** for field horticulture and **0.4 tons** in 2060 compared to 2020 for orchards and citrus groves.

Table 5.11 Use of active substances of plant protection for organic agriculture (tons).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Other Arable Crops – Organic	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
Cereals - Organic	0.44	0.49	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.47
Orchards And Citrus Groves - Organic	5.37	3.93	3.74	3.71	3.68	3.65	3.62	3.60	3.57	3.54
Horticulture In The Field - Organic	2.70	5.63	5.35	5.31	5.27	5.23	5.19	5.15	5.11	5.07
Olive Growing - Organic	0.38	0.52	0.54	0.55	0.55	0.56	0.56	0.56	0.57	0.57
Viticulture - Organic	0.55	1.18	1.12	1.11	1.10	1.09	1.08	1.08	1.07	1.06

Total irrigation water (Table 5.12) shows **a 10%** decrease in 2060 compared to 2020 (corresponding to about **9’097’732 m^3**). The lower demand of irrigation water corresponds to a **10%** decrease of land use both for orchards and citrus groves and horticulture. As regards the distribution of irrigation water, there is a **58%** reduction, (**-5’233’381 m^3**) related to conventional orchards and citrus groves, **17%** (**-1’555’856 m^3**) to conventional horticulture in the field, **13%** (**-1’142’036 m^3**) to organic orchards and citrus groves, **11%** (**-1’035’492 m^3**) to organic horticulture in the field and **1%** (**-130’966**

m^3) to conventional horticulture in the greenhouse.

Table 5.12 Water consumption for irrigation (m^3).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Orchards And Citrus Groves – Conven.	71642879	52333811	49717120	49343307	48969494	48595681	48221868	47848055	47474242	47100430
Orchards And Citrus Groves - Organic	11128875	11420364	10849345	10767771	10686197	10604623	10523049	10441475	10359901	10278327
Field Horticulture – Conven.	24508333	15558556	14780628	14669496	14558363	14447231	14336098	14224965	14113833	14002700
Greenhouse Horticulture – Conven.	24508333	15558556	14780628	14669496	14558363	14447231	14336098	14224965	14113833	14002700
Field Horticulture – Organic	5463386	10354924	9837178	9763214	9689250	9615287	9541323	9467359	9393395	9319432
Total Irrigation Water	**114888924**	**90977316**	**86428450**	**85778613**	**85128775**	**84478937**	**83829099**	**83179261**	**82529423**	**81879585**

As for livestock (Figure 5.2), water consumption is constant over the time horizon with no changes in the distribution compared to 2020. In particular, cattle consume **63%** of the total water for livestock [**5’709’698 m^3**], swine **22%** [**1’999’517 m^3**], sheep **12%** [**1’095’267 m^3**] and goats **3%** [**268’582 m^3**].

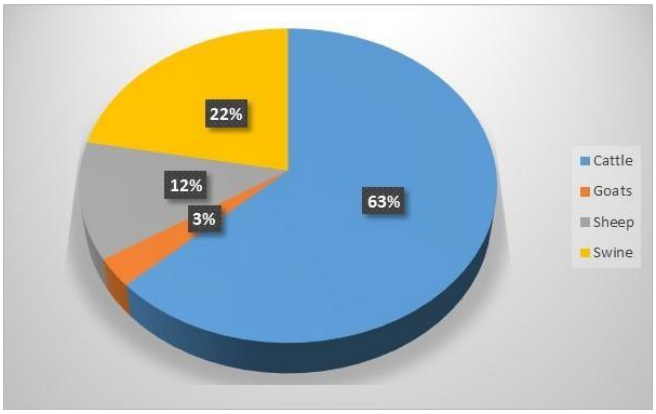

Figure 5.2 Percentage of water consumption by livestock species.

The total production of waste by crops decreases by **7%** over the time horizon, achieving about **498’462 tons** in 2060 (Table 5.13). This reduction is mainly due to an increase in the use of land for permanent meadows and pastures, optimal solution of the model, which is characterized by the absence of waste production compared to other agricultural productions. In 2060 the cultivation of conventional cereals shows a reduction of **31’160** tons compared to 2020, followed by that of organic cereals (**-3’426 tons**), other conventional arable crops (**-2’878 tons**), conventional orchards and citrus groves (**-1’951 tons**), organic orchards and citrus groves (**-570 tons**), conventional viticulture (**-515 tons**) and organic viticulture (**-390 tons**). Waste production from conventional olive growing and organic olive growing respectively increase by **3'481** tons and **1'184** tons in 2060 compared to 2020.

Table 5.13 Waste production by crops (tons).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Other Arable Crops – Conven.	18935	28785	27345	27140	26934	26729	26523	26317	26112	25906
Other Arable Crops – Organic	9954	4586	4357	4324	4291	4258	4226	4193	4160	4127
Cereals – Conven.	311264	311598	296018	293792	291567	289341	287115	284889	282664	280438
Cereals - Organic	99258	109273	107560	107315	107070	106825	106581	106336	106091	105846
Orchards And Citrus Groves – Conven.	25457	19514	18538	18399	18259	18120	17981	17841	17702	17562
Orchards And Citrus Groves - Organic	7772	5698	5414	5373	5332	5291	5251	5210	5169	5129
Olive Growing – Conven.	43241	34806	36546	36795	37043	37292	37540	37789	38038	38286
Olive Growing - Organic	8776	11839	12431	12515	12600	12685	12769	12854	12938	13023
Viticulture – Conven.	8458	5152	4894	4857	4820	4784	4747	4710	4673	4636
Viticulture - Organic	1836	3897	3703	3675	3647	3619	3591	3563	3536	3508
Total Waste	**534951**	**535147**	**516805**	**514184**	**511564**	**508944**	**506323**	**503703**	**501083**	**498462**

Total CO_2 emissions decrease by **4%** in 2060 (about **- 4 tons** compared to 2020) due to the reduction in diesel consumption over the time horizon (Table 5.14). There is a smaller reduction in total N_2O emissions, mainly related to nitrogen fertilizers, while total CH_4 emissions mainly due to livestock are almost constant.

Table 5.14 Total emissions (ktons).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
CO_2	121	110	108	107	107	107	107	106	106	106
N_2O	0.346	0.348	0.344	0.343	0.343	0.342	0.341	0.341	0.340	0.340
CH_4	11.28	11.30	11.30	11.30	11.30	11.30	11.30	11.30	11.30	11.30

The distribution of CH_4 emission by source does not change between 2020 and 2060 (Figure 5.3). Enteric fermentation contributes **84%** to the release of CH_4 emissions, while manure management for **15.5%** and the contribution of energy consumption is negligible (**0.2%**).

As for N_2O emissions, the use of fertilizers contributes **76%** in 2020 and **75%** in 2060. The contribution of manure management increases from **18%** in 2020 to **19%** in 2060, while emissions from energy consumption are almost constant (**6%**) over time horizon.

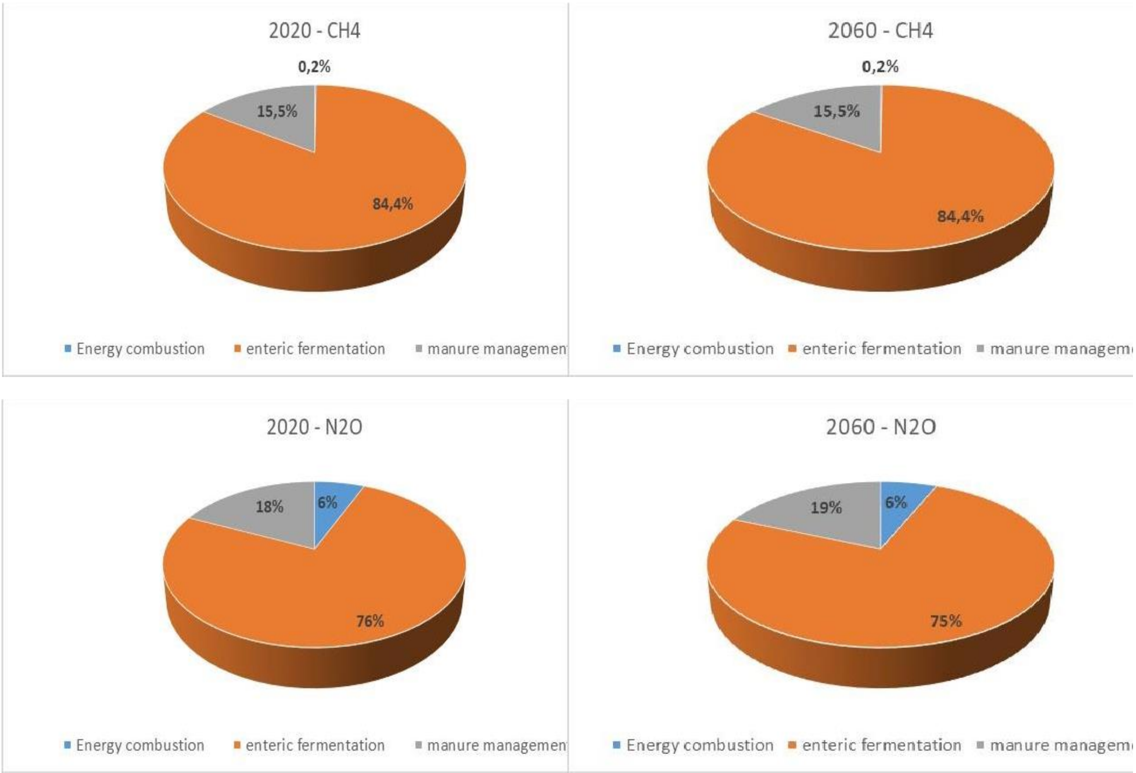

Figure 5.3 CH_4 and N_2O emissions by source (2020 -2060).

The total system cost estimated by the model (the least cost solution) is **2'089 MEuro**, showing a **6%** reduction of the total annual costs in 2060 compared to 2020, corresponding to **16.13 MEuro** (table 5.15).

Cost reduction is mainly due to the decrease in water supply (**-8.10 MEuro**), crop production (**-5.46 MEuro**), crop protection (**-1.28 MEuro**) and energy consumption (**-1.18 MEuro**).

Table 5.15 Costs for the main categories (MEuro).

	2010	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**
Energy consumption	41.5	33.7	33.1	33.0	32.9	32.8	32.7	32.6	32.6	32.5
Fertilizers	3.3	3.0	2.9	2.9	2.9	2.9	2.9	2.9	2.9	2.9
Crop protection	22.4	18.9	18.3	18.2	18.1	18.0	17.9	17.8	17.7	17.6
Water supply	74.3	89.0	85.0	84.4	83.8	83.3	82.7	82.1	81.5	80.9
Livestock	56.8	56.4	56.4	56.4	56.4	56.4	56.4	56.4	56.4	56.4
Crop production	86.9	73.1	70.4	70.0	69.6	69.2	68.8	68.5	68.1	67.7
Total Costs	**285.3**	**274.1**	**266.1**	**264.9**	**263.8**	**262.6**	**261.5**	**260.3**	**259.2**	**258.0**

5.2 Policy scenarios: main results

This paragraph shows the results obtained for two constrained scenarios analysing the effects of the Farm to Fork strategy on the configuration of the water-energy-food system.

The FERT_10 scenario, which provides for a 10% reduction in the use of fertilizers by 2030 compared to 2020 values, is designed to test the effect of this constraint on land use before introducing an additional exogenous constraint on organic production. The PEST_50 is built by imposing a 50% reduction in the use of active substances in plant protection for conventional and organic cultivation process.

Figure 5.4 shows the distribution of land use between conventional and organic productions resulting from the constraints imposed in the two scenarios.

In the FERT_10 scenario, the total land use for conventional production decreases by **0.5%** in 2025 (**-1'424 ha**) and by **0.7%** in 2030 (**-2'189 ha**) compared to the BAU scenario. A larger decrease is observed in PEST_50: **-4.8%** in 2025 (**-14'205 ha**) and **10.1**% in 2030 (**-29'777 ha**) compared to the BAU scenario.

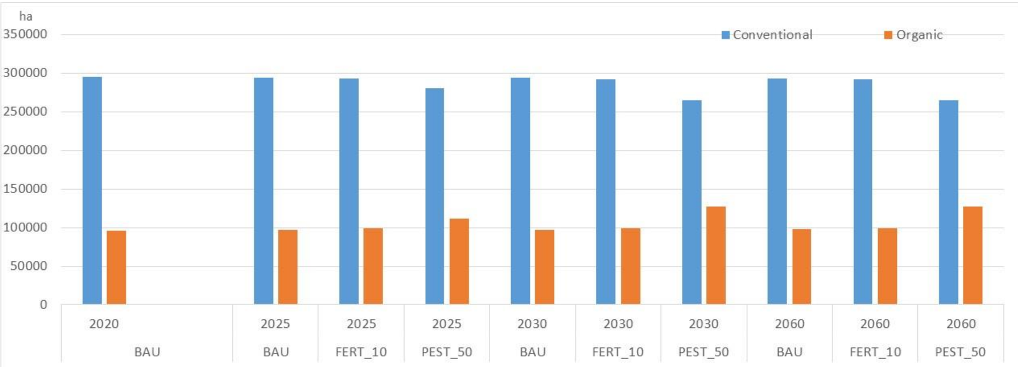

Figure 5.4 Comparison of total land use (ha) in the BAU, FERT_10 and PEST_50 scenarios.

For organic production, total land use increases in both the FERT_10 and in PEST_50 scenarios. In the FERT_10 scenario it increases by **1.5%** in 2025 and by **2.3%** in 2030 compared to the BAU scenario while in the PEST_50 scenario the increase is **14.6%** in 2025 and **30.6%** compared to the BAU scenario.

Analyzing the single crops, it is observed that the use of land for conventional cereals shows a greater reduction in absolute value both in the FERT_10 and in the PEST_50 scenarios compared to the BAU (Figure 5.5).

In 2025 the decrease is **-18'276 ha** (**-15.8%**) in FERT_10 and **-25'587 ha** (**-22.1%**) in

PEST_50 respectively. This decrease in 2030 reaches **-39'338 ha (-34.2%**) in FERT_10 and **-55'177 ha (-48%**) in PEST_50. In 2060 land use decrease **-34'116 ha (-31.1%**) in FERT_10 and **49'955 ha** (**-45.6%)** in PEST_50.

A different trend is shown by organic cereal crops. In FERT_10 land use for cereal crops decreases **10.7%** (**-3'925 ha**) in 2025, **23.6%** (**-8'607 ha**) in 2030 and **22.5%** (**-8'108 ha**) in 2060 respect to BAU.

In PEST_50, on the other hand, land use for cereals increases by **21.6%** in 2025 (**+ 7'904 ha**), by **44.4%** in 2030 (**+ 16'190 ha**) and **46.4%** in 2060 (**+ 16'689 ha**).

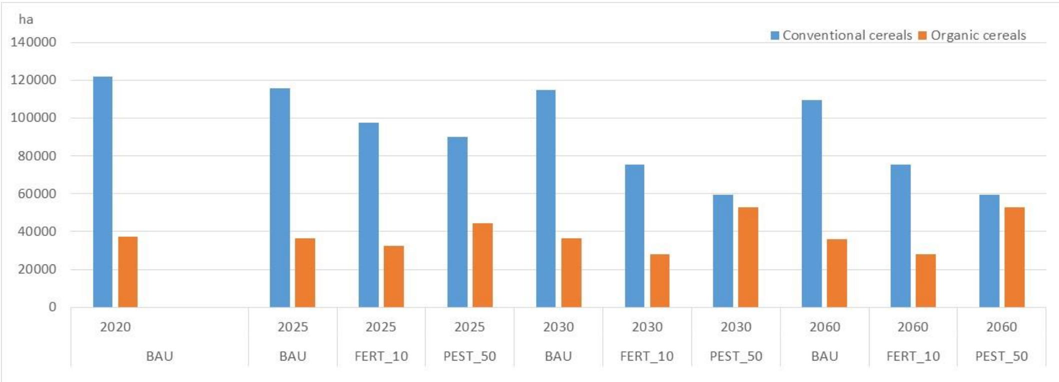

Figure 5.5 Comparison of land use of cereals (ha) in the BAU, FERT_10 and PEST_50 scenarios.

As for the other arable crops (Figure 5.6), land use in the two policy scenarios decreases both for conventional and organic farming compared to BAU over the entire time horizon.

In FERT_10 the decrease is **15.8%** in 2025 (respectively **-276 ha** for conventional other arable crops and **-30 ha** for organic other arable crops) and **31.1%** in 2060 (respectively **-516 ha** for conventional other arable crops and **-57 ha** for organic other arable crops) while it is **-22.1%** in 2025 (respectively **-387 ha** for conventional other arable crops and **-42 ha** for organic other arable crops) and **-45.6%** (respectively **-756 ha** for conventional other arable crops and **-83 ha** for organic other arable crops) in 2060 for PEST_50.

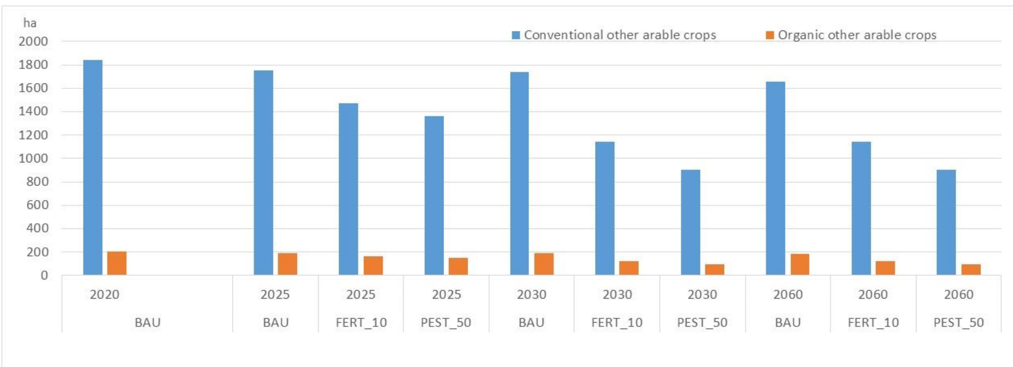

Figure 5.6 Comparison of other arable crops land use (ha) in BAU, FERT_10 and PEST_50 scenarios

Forage crops meet the food needs of livestock and the constraints of the policy scenarios imply a shift of the hectares used by conventional crops to organic crops (Figure 5.7).

In particular, in FERT_10 land use shift from conventional to organic crops compared to BAU is **1'351 ha** in 2025 and **1'038 ha** in 2060.

This trend is more evident in PEST_50 where the shift between conventional and organic land use is **2'792 ha** in 2025 and **5'452 ha** in 2060 respect to BAU.

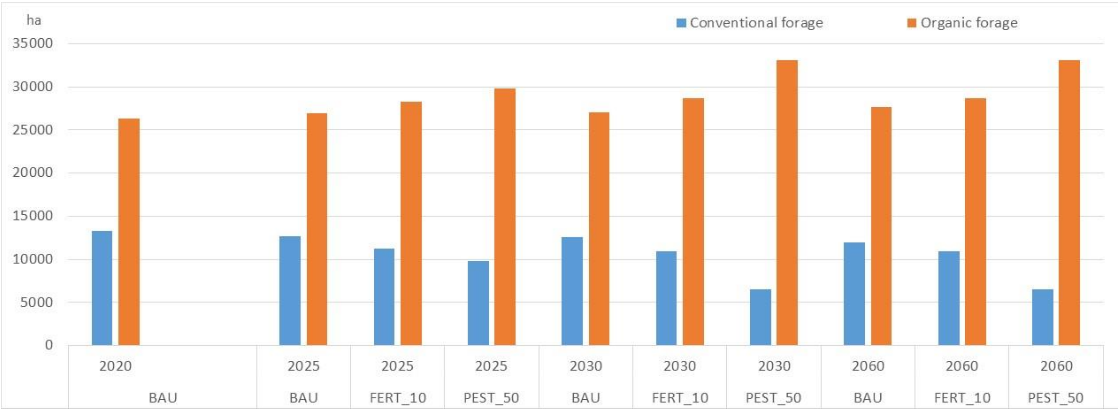

Figure 5.7 Comparison of forage land use (ha) in the BAU, FERT_10 and PEST_50 scenarios.

Land use for conventional horticulture also decreases both in open field and in greenhouse over the time horizon (Figure 5.8). Field horticulture, in FERT_10 decreases (**844 ha** in 2025, **1'817 ha** in 2030 and **1'576 ha** in 2060) while in PEST_50 the decrease is **2'549 ha** in 2025, **1'182 ha** in 2030 and **2'308 ha** in 2060.

The same trend is observed for greenhouse horticulture in both scenarios even if with lower values (**-55 ha** in 2025, **-230 ha** in 2030 and **-199 ha** in 2060 in FERT_10 and **-322 ha** in 2025, **-149 ha** in 2030 and **-292 ha** in 2060 in PEST_50).

On the other hand, organic field horticulture shows a different trend over the time horizon in FERT_10. In fact, there is a decrease in 2025 (**-305 ha)** followed by an increase (+**234 ha** in 2030 and **+398 ha** in 2060). On the other hand, for organic horticulture similar to conventional horticulture, the introduction of a restriction on the use of pesticides leads to a reduction of **-806 ha** in 2025, **-1'738 ha** in 2030 and **-1'574 ha** in 2060.

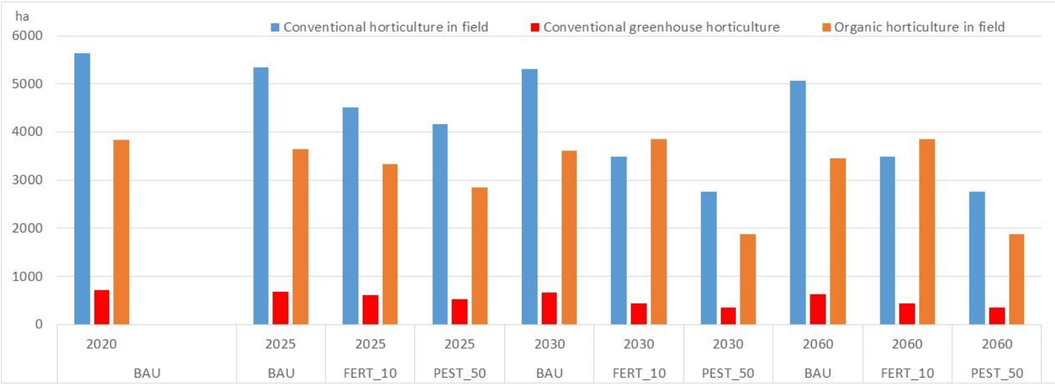

Figure 5.8 Comparison of horticulture land use (ha) in the BAU, FERT_10 and PEST_50 scenarios.

Conventional orchards and citrus groves also show a decrease in land use in both scenarios respect to BAU (Figure 5.9). In FERT_10 the decrease is – **1’788 ha** in 2025 and **-2’503 ha** in 2060 while in PEST_50 it is **-2’503 ha** in 2025 and **-4’887 ha** in 2060.

For organic orchards and citrus groves, the variations in land use in response to the application of policy constraints are different for the two scenarios. In fact, in FERT_10 land use increases (**+764 ha** in 2025, **+1’336 ha** in 2030 and **+1’467 ha** in 2060), while in PEST_50 there is a reduction (**-642 ha** in 2025, **-1’384 ha** in 2030 and **-1’253 ha** in 2060).

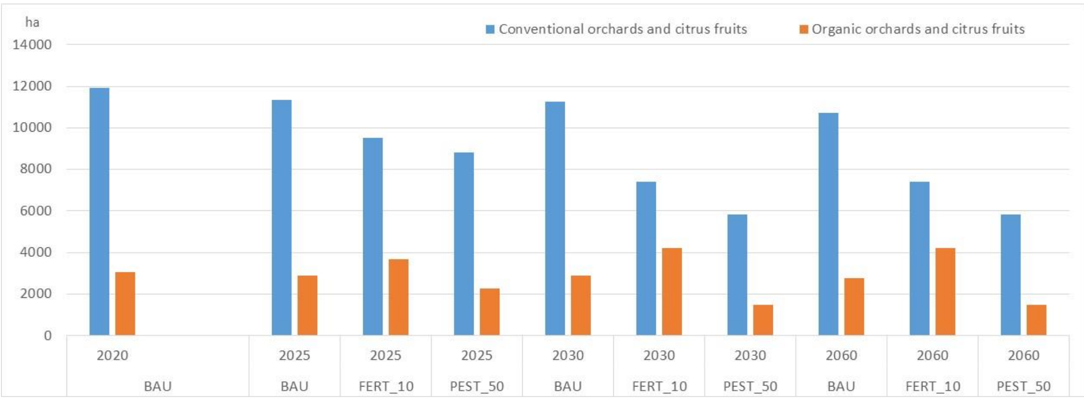

Figure 5.9 Comparison of orchards and citrus groves land use (ha) in the BAU, FERT_10 and PEST_50 scenarios.

Land use of olive growing increases for both for conventional and organic crops in FERT_10 compared to the BAU scenario (Figure 5.10). In particular, for conventional olive growing the increase is **+3’321 ha** in 2025, **+7’149 ha** in 2025 and **+6’200 ha** in 2060 while for organic olive growing it is **+820 ha** in 2025, **+1’765 ha** in 2030 and **+1’531 ha** in 2060.

In PEST_50, land use for conventional crops decreases over the time horizon (**-1’107 ha** in 2025, **-5’857 ha** in 2030 and **-12’384 ha** in 2060), while for organic crops it is observed a decrease in 2025 (–**273 ha**) and then an increase (respectively **+1’109 ha** in 2030 +**2’242 ha** and 2060).

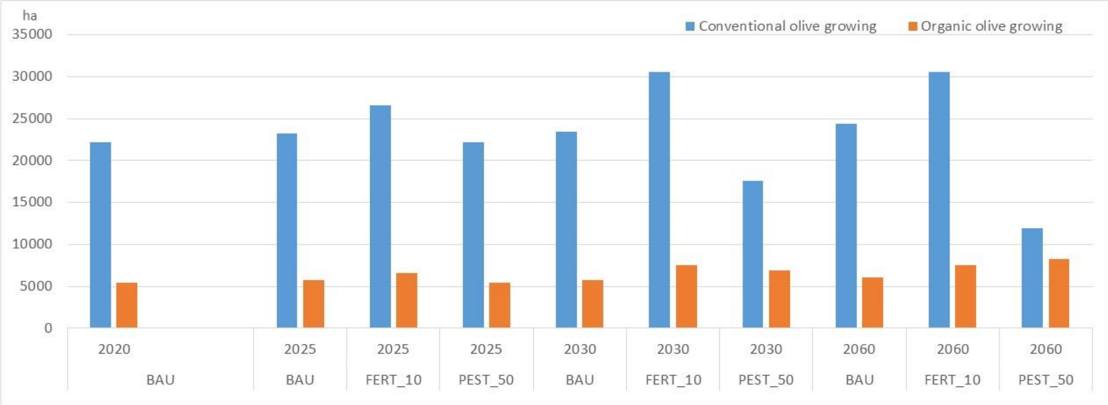

Figure 5.10 Comparison of land use for conventional and organic olive growing (ha) in the BAU, FERT_10 and PEST_50 scenarios.

In FERT_10, viticulture has a different response than other crops. In particular, land use increases over the time horizon (**+397 ha** in 2025, **+541 ha** in 2030 and **+609 ha** in 2060) in conventional viticulture, while it decreases in organic viticulture (**-140 ha** in 2025, **-300 ha** in 2030 and **-260 ha** in 2060).

In PEST_50, both conventional and organic viticulture are decreasing (**-333 ha** in 2025, **-718 ha** in 2030 and **-650 ha** in 2060 for conventional viticulture and **-195 ha** in 2025, **-421 ha** in 2030 and **-381 ha** in 2060 for organic viticulture).

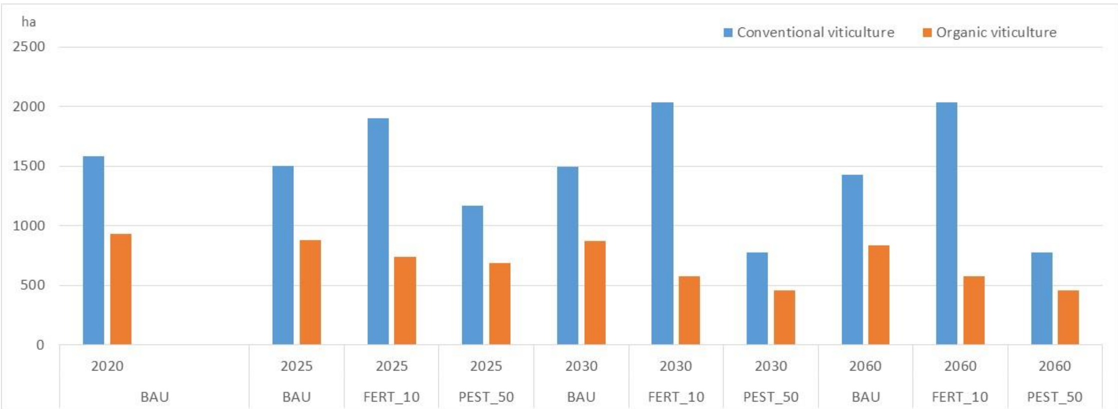

Figure 5.11 Comparison of land use for conventional and organic viticulture (ha) in the BAU, FERT_10 and PEST_50 scenarios.

Permanent meadows and pastures show the highest increases in land use for both conventional and organic crops in both FERT_10 and PEST_50 scenarios (Figure 5.12). In FERT_10 the increase for conventional crops is respectively **+ 17’449 ha** in 2025, **+ 37’556 ha** in 2030 and **+ 32’571 ha** in 2060 while for organic crops it is **+2’890 ha** in 2025, **+ 6’220 ha** in 2030 and **+5’394 ha** in 2060.

In PEST_50, land use increases respect to FERT_10: **+24’428 ha** in 2025, **+52’679 ha** in 2030 and **+47’693 ha** in 2060 for conventional crops and **+4’045 ha** in 2025, **+8’724 ha** in 2030 and **+7’898 ha** in 2060 for organic crops.

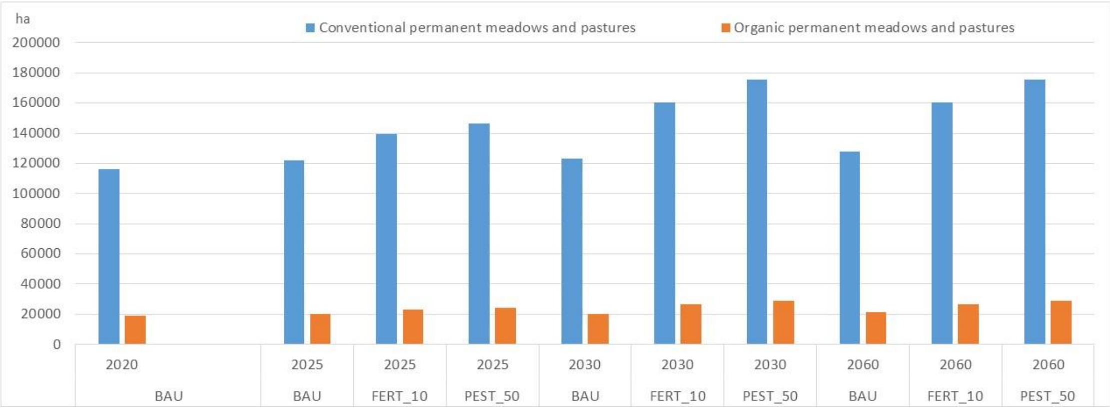

Figure 5.12 Land use (ha) of conventional and organic permanent meadows and pastures in the BAU, FERT_10 and PEST_50 scenarios.

Table 5.16 shows land use changes for all categories in the FERT_10 and PEST_50 scenarioscompared to the BAU scenario in 2060. In particular, land use for conventional cereals shows the highest decrease in absolute value both in the FERT_20 and PEST_50 scenarios compared to BAU, while a different trend is observed for organic cereal crops. Permanent meadows and pastures show the highest increase for both conventional and organic crops in both the FERT_20 and PEST_50 scenarios.

Table 5.16 Land use variations in 2060 (ha).

	FERT_10	PEST_50
Conventional other arable crops	-700	-940
Organic other arable crops	-77	-103
Conventional cereals	-46’300	-62’139
Organic cereals	-9’273	15’525
Conventional forage	-2’368	-6’781
Organic forage	2’368	6’781
Conventional orchards and citrus groves	-4’530	-6’079
Organic orchards and citrus groves	1’161	-1’559
Conventional field horticulture	-2’139	-2’871
Conventional greenhouse horticulture	-270	-363
Organic field horticulture	14	-1957
Conventional olive growing	8’414	-10’170
Organic olive growing	2’078	2’789
Conventional permanent meadows and pastures	44’204	59’326
Organic permanent meadows and pastures	7’320	9’825
Conventional viticulture	451	-809
Organic viticulture	-353	-474

The variations of agricultural products in the two policy scenarios with respect to the BAU proportionally follow the trend of land use.

Diesel consumption shows a decrease in the FERT_10 and PEST_50 scenarios: respectively **-0.07 PJ** in 2025, **-0.16 PJ** in 2030 (the highest reduction) and **– 0.13 PJ** in 2060 for FERT_10, **-0.11 PJ** in 2025, **-0.25 PJ** in 2030 (the highest reduction) and **–0.22 PJ** in 2060 for PEST_50 (Figure 5.13).

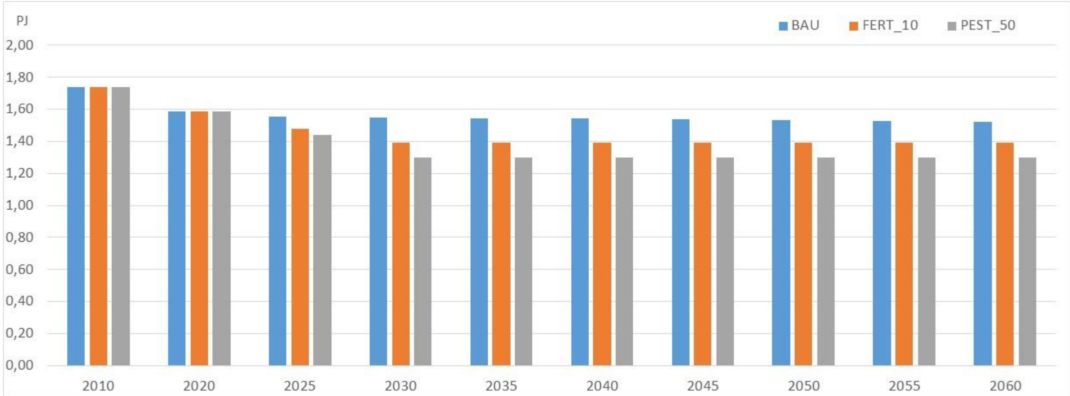

Figure 5.13 Diesel consumption (PJ) in in the BAU, FERT_10 and PEST_50 scenarios.

Diesel consumption for crop production decreases **0.06 PJ** in 2025, **0.14 PJ** in 2030, **0.12 PJ** in 2060 in FERT_10 and **0.09 PJ** in 2025, **0.19 PJ** in 2030, **0.17 PJ** in 2060 in PEST_50 (Table 5.17). The variations in consumption for irrigation are smaller, while theconsumption of diesel fuel for livestock is constant.

Table 5.17 Diesel consumption for the aggregated categories (PJ).

		2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
BAU	Crop production	1.34	1.26	1.24	1.24	1.23	1.23	1.23	1.22	1.22	1.22
	Livestock	0.22	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	019
	Irrigation	0.18	0.13	0.13	0.13	0.12	0.12	0.12	0.12	0.12	0,12
FERT_10	Crop production	1.34	1.26	1.18	1.10	1.10	1.10	1.10	1.10	1.10	1.10
	Livestock	0.22	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
	Irrigation	0.18	0.13	0.12	0.10	0.10	0.10	0.10	0.10	0.10	0.10
PEST_50	Crop production	1.34	1.26	1.15	1.05	1.05	1.05	1.05	1.05	1.05	1.05
	Livestock	0.22	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
	Irrigation	0.18	0.13	0.10	0.07	0.07	0.07	0.07	0.07	0.07	0.07

In the two scenarios FERT_10 and PEST_50, a high reduction of irrigation water is observed compared to the BAU scenario (table 5.18). In particular, in FERT_10 the decrease is **-10%** (–8’253’416 m^3) in 2025, **-19% (-16’719’556 m^3)** in 2030 and **-16%** (-12’820’528 m^3) in 2060.

In the PEST_50 scenario, a more marked reduction is observed ranging from **-22%** (-

19’105’236 m^3) in 2025, to **-48%** (-41’199’728 m^3) in 2030, being equal to **-46%** (-37’300 ‘700 m^3) in 2060.

Table 5.18 Water consumption for irrigation (m^3).

	2010	2020	2025	2030	2035	2040	2050	2055	2060
BAU	114888924	90977316	86428450	85778613	85128775	84478937	83179261	82529423	81879585
FERT_10	114888924	90977316	78175034	69059056	69059056	69059056	69059056	69059056	69059056
PEST_50	114888924	90977316	67323214	44578885	44578885	44578885	44578885	44578885	44578885

By comparing the consumption of irrigation water for the different crops in 2030 (year characterized by the greatest reductions) and in 2060 (Table 5.19), it is possible to observe a reduction in the consumption of irrigation water for conventional crops both in the FERT_10 scenario and in the PEST_50 scenario, while for organic crops, there is an increase in the FERT_10 scenario and reduction in the PEST_50 scenario. Orchards and citrus groves, on the other hand, show a greater reduction in both the FERT_10 and PEST_50 scenarios.

Table. 5.19 Consumption of irrigation water by crop (m^3) in FERT_10 and PEST_50 scenarios.

	FERT_10		PEST_50	
	2030	2060	2030	2060
Conventional orchards and citrus groves	-16'896’345	-14’653’467	-23’699’740	-21’456’862
Organic orchards and citrus groves	4’992’330	5'481’775	-5'171’793	-4'682’349
Conventional field horticulture	-5'023’191	-4’356’396	-7’045’803	-6’379’008
Conventional greenhous horticulture	-422’834	-366’705	-593’090	-536’961
Organic field horticulture	630’483	1’074’265	-4’689’301	-4’245’519

By applying a 5% reduction in the use of nitrogen fertilizers by 2025 and 10% by 2030 compared to 2020, in the FERT_10 scenario, there is a decrease of **-604 tons** in 2025 and **-1’407 tons** in 2030 compared to the BAU scenario (Table 5.20). Greater reductions of nitrogen fertilizers are obtained in the PEST_50 scenario (**-987 tons** in 2025 and **-2’128 tons** in 2030).

Table 5.20 Total consumption of nitrogen fertilizers for each scenario (tons).

	2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
BAU	16’808	16’716	16’484	16’451	16’418	16’385	16’351	16’318	16’285	16’252
FERT_10	16’808	16’716	15’880	15’044	15’044	15’044	15’044	15’044	15’044	15’044
PEST_50	16’808	16’716	15’496	14’322	14’322	14’322	14’322	14’322	14’322	14’322

In Tables 5.21 and 5.22 are reported the variations in the consumption of nitrogen fertilizers in FERT_10 and PEST_50 respect to BAU, respectively in percentage and absolute value.

Table 5.21 Percentage variation of nitrogen fertilizers in FERT_10 and PEST_50 scenarios compared to BAU.

	FERT_10		PEST_50	
	2025	**2030**	**2025**	**2030**
Conventional other arable crops – nitrogen fertilizers	-16%	-34%	-22%	-48%
Organic other arable crops – nitrogen fertilizers	-16%	-34%	-22%	-48%
Conventional cereals – nitrogen fertilizers	-16%	-34%	-22%	-48%
Organic cereals – nitrogen fertilizers	-11%	-24%	+22%	+44%
Conventional forage – nitrogen fertilizers	-11%	-13%	-22%	-48%
Organic forage – nitrogen fertilizers	+5%	+6%	+10%	+22%
Conventional orchards and citrus groves – nitrogen fertilizers	-16%	-34%	-22%	-48%
Organic orchards and citrus groves – nitrogen fertilizers	+26%	+46%	-22%	-48%
Conventional field horticulture – nitrogen fertilizers	-16%	-34%	-22%	-48%
Organic field horticulture – nitrogen fertilizers	-8%	+6%	-22%	-48%
Conventional olive growing – nitrogen fertilizers	+14%	+31%	-25%	-49%
Organic olive growing – nitrogen fertilizers	+14%	+31%	+20%	+43%
Conventional viticulture – nitrogen fertilizers	+26%	+36%	-22%	-48%
Organic viticulture – nitrogen fertilizers	-16%	-34%	-22%	-48%
Conventional permanent meadows and pasture – nitrogen fertilizers	+14%	+31%	+20%	+43%

Table 5.22 Variation of nitrogen fertilizers (ton) in FERT_10 and PEST_50 scenarios compared to BAU.

	FERT_10		PEST_50	
	2025	**2030**	**2025**	**2030**
Conventional other arable crops – nitrogen fertilizers	-81	-173	-113	-243
Organic other arable crops – nitrogen fertilizers	-20	-42	-27	-59
Conventional cereals – nitrogen fertilizers	-906	-1’951	-1’269	-2’736
Organic cereals – nitrogen fertilizers	-193	-424	389	798
Conventional forage – nitrogen fertilizers	-54	-64	-111	-239
Organic forage – nitrogen fertilizers	58	69	119	257
Conventional orchards and citrus groves – nitrogen fertilizers	-128	-275	-179	-386
Organic orchards and citrus groves – nitrogen fertilizers	54	95	-46	-98
Conventional field horticulture – nitrogen fertilizers	-28	-60	-39	-84
Conventional greenhouse horticulture – nitrogen fertilizers	-22	-94	-61	-132
Organic field horticulture – nitrogen fertilizers	-5	4	-14	-30
Conventional olive growing – nitrogen fertilizers	168	362	-288	-579
Organic olive growing – nitrogen fertilizers	37	80	52	112
Conventional viticulture – nitrogen fertilizers	55	75	-46	-100
Organic viticulture – nitrogen fertilizers	-19	-41	-27	-58
Conventional permanent meadows and pasture – nitrogen fertilizers	480	1034	672	1450

Table 5.23 shows the share of nitrogen fertilizers for each crop resulting from the policy constraints. In particular, the crops that contribute most to the 10% reduction of the total use of nitrogen fertilizers are highlighted.

Table 5.23 Share of nitrogen fertilizers for the different crops in the FERT_10_PEST_50 and BAU scenarios.

	2025			2030		
	BAU	**FERT_10**	**PEST_50**	**BAU**	**FERT_10**	**PEST_50**
Conventional other arable crops	3%	3%	3%	3%	2%	2%
Organic other arable crops	1%	1%	1%	1%	1%	0%
Conventional cereals	**35%**	**30%**	**29%**	**35%**	**25%**	**21%**
Organic cereals	11%	10%	14%	11%	9%	18%
Conventional forage	3%	3%	3%	3%	3%	2%
Organic forage	7%	8%	8%	7%	8%	10%
Conventional orchards and citrus groves	5%	4%	4%	5%	4%	3%
Organic orchards and citrus groves	1%	2%	1%	1%	2%	1%
Conventional field horticulture	1%	1%	1%	1%	1%	1%
Conventional greenhouse horticulture	2%	2%	1%	2%	1%	1%
Organic field horticulture	0%	0%	0%	0%	0%	0%
Conventional olive growing	7%	8%	6%	7%	10%	4%
Organic olive growing	2%	2%	2%	2%	2%	3%
Conventional viticulture	1%	2%	1%	1%	2%	1%
Organic viticulture	1%	1%	1%	1%	1%	0%
Conventional permanent meadows and pasture	**20%**	**24%**	**26%**	**21%**	**29%**	**34%**

A greater reduction in the use of nitrogen fertilizers is observed for **conventional cereals** while a greater increase is noticed for **conventional permanent meadows and pastures**. In FERT_10 nitrogen fertilizers are more used for conventional cereals (**29%** in 2030) thanin permanent grassland and conventional pasture (**26%** in 2030). This trend changes in PEST_50, in which **conventional permanent meadows and pastures** account for **34%** of the total nitrogen consumption while conventional cereals for **21%**.

The use of nitrogen fertilizers increases also for organic olive growing in both scenarios, ranging between **2%** and **3%** of total consumption. Conventional olive growing shows an increase in FERT_10 (**+168 tons** in 2025 and **+362 tons** in 2030) and a reduction in PEST_50 (**-288 tons** in 2025 and **-579 tons** in 2030). Moreover, in PEST_50, there is a remarkable increase in organic cereals and organic forage more evident in 2030 (**+798 tons** for organic cereals and **+257 tons** for organic forage).

On the other hand, the use of phosphate fertilizers decreases **-20 tons** in 2025 and **-63 tons** in 2030 for the FERT_10 scenario and **-191 tons** in 2025 and **-406 tons** in 2030 for the PEST_50 scenario (Table 5.24).

Table 5.24 Total consumption of phospathe fertilizers for each scenario (tons).

		2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
BAU		1136	933	907	903	899	896	892	888	884	881
FERT_10		1136	933	887	840	840	840	840	840	840	840
PEST_50		1136	933	716	497	497	497	497	497	497	497

Table 5.25 Percentage variation of phosphate fertilizers in FERT_10 and PEST_50 scenarios compared to BAU.

	FERT_10		PEST_50	
	2025	2030	2025	2030
Conventional other arable crops – phosphate fertilizers	-16%	-34%	-22%	-48%
Conventional cereals – phosphate fertilizers	-16%	-34%	-22%	-48%
Organic cereals – phosphate fertilizers	-11%	-24%	22%	44%
Conventional forage – phosphate fertilizers	-11%	-13%	-22%	-48%
Conventional orchards and citrus groves – phosphate fertilizers	-16%	-34%	-22%	-48%
Organic orchards and citrus groves – phosphate fertilizers	26%	46%	-22%	-48%
Conventional field horticulture – phosphate fertilizers	-16%	-34%	-22%	-48%
Conventional greenhouse horticulture – phosphate fertilizers	-8%	-34%	-22%	-48%
Organic field horticulture – phosphate fertilizers	-8%	6%	-22%	-48%
Conventional olive growing – phosphate fertilizers	14%	31%	-25%	-49%
Organic olive growing – phosphate fertilizers	14%	31%	20%	43%
Conventional viticulture – phosphate fertilizers	26%	36%	-22%	-48%
Organic viticulture – phosphate fertilizers	-16%	-34%	-22%	-48%

Table 5.26 Variations of phosphate fertilizers (tons) in FERT_10 and PEST_50 scenarios compared to BAU.

	FERT_10		PEST_50	
	2025	2030	2025	2030
Conventional other arable crops – phosphate fertilizers	-0.8	-1.8	-1.2	-2.5
Conventional cereals – phosphate fertilizers	-24.1	-51.9	-33.7	-72.7
Organic cereals – phosphate fertilizers	-1.3	-2.8	2.6	5.2
Conventional forage – phosphate fertilizers	-1.5	-1.8	-3.1	-6.8
Conventional orchards and citrus groves – phosphate fertilizers	-35.2	-75.7	-49.2	-106.2
Organic orchards and citrus groves – phosphate fertilizers	20.9	36.6	-17.6	-37.9
Conventional field horticulture – phosphate fertilizers	-6.8	-14.6	-9.5	-20.5
Conventional greenhouse horticulture – phosphate fertilizers	-6.3	-26.3	-17.1	-36.9
Organic field horticulture – phosphate fertilizers	-2.9	2.3	-7.8	-16.7
Conventional olive growing – phosphate fertilizers	26.9	57.9	-46.2	-92.6
Organic olive growing – phosphate fertilizers	2.9	6.1	4.0	8.6
Conventional viticulture – phosphate fertilizers	10.6	14.5	-8.9	-19.3
Organic viticulture – phosphate fertilizers	-2.6	-5.7	-3.7	-8.0

Table 5.27 Breakdown of phosphate fertilizer for the different crops in the FERT_10_PEST_50 and BAU scenarios.

	2025			**2030**		
	BAU	**FERT_10**	**PEST_50**	**BAU**	**FERT_10**	**PEST_50**
Conventional other arable crops	1%	1%	1%	1%	0%	1%
Conventional cereals	17%	14%	17%	17%	12%	16%
Organic cereals	1%	1%	2%	1%	1%	3%
Conventional forage	2%	1%	2%	2%	1%	1%
Conventional orchards and citrus groves	**25%**	**21%**	**24%**	**24%**	**17%**	**23%**
Organic orchards and citrus groves	9%	11%	9%	9%	14%	8%
Conventional field horticulture	5%	4%	5%	5%	3%	4%
Conventional greenhouse horticulture	9%	8%	8%	8%	6%	8%
Organic field horticulture	4%	4%	4%	4%	4%	4%
Conventional olive growing	**21%**	**24%**	**20%**	**21%**	**29%**	**20%**
Organic olive growing	2%	3%	3%	2%	3%	6%
Conventional viticulture	4%	6%	4%	4%	7%	4%
Organic viticulture	2%	2%	2%	2%	1%	2%

As highlighted in Table 5.26 and Table 5.27, phosphate fertilizers use is more reduced in conventional orchards and citrus groves (**-35.2 tons** in 2025 and **-75.7 tons** in 2030 in FERT_10 and **-49.2 tons** in 2025 and **-106.2 tons** in 2030 in PEST_50) and conventional olive growing (**-46.2 tons** in 2025 and **-92.6 tons** in 2030 in PEST_50). Phosphate fertilizers use increases in organic olive growing both in FERT_10 (**+2.9 tons** in 2025 and **+6.1 tons** in 2030) and in PEST_50 (**+4 tons** in 2025 and **+8.6 tons** in 2030). Organic orchards and citrus groves and conventional olive growing show the highest increase of phosphate fertilizers in FERT_10 (respectively **+20.9 tons** in 2025 and **+36.6 tons** in 2030 and **+26.9 tons** in 2025 and **+57.9 tons** in 2030). In PEST 50, most of the crops show a decrease in the use of phosphate fertilizers.

The overall reduction in potash compared to the BAU scenario is **-18 tons** in 2025 and **-61 tons** in 2030 in FERT_10 and **-190 tons** in 2025 and **-405 tons** in 2030 in PEST_50 (Table 5.28).

Table 5.28 Total consumption of potash fertilizers (tons).

	2010	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**
BAU	1167	952	922	917	913	909	905	900	896	892
FERT_10	1167	952	904	857	857	857	857	857	857	857
PEST_50	1167	952	731	512	512	512	512	512	512	512

Table 5.29 Percentage variation of potash fertilizers use in FERT_10 and PEST_50 scenarios compared to BAU.

	FERT_10		PEST_50	
	2025	**2030**	**2025**	**2030**
Conventional cereals – potash fertilizers	-16%	-34%	-22%	-48%
Organic cereals – potash fertilizers	-11%	-24%	22%	44%
Conventional forage – potash fertilizers	-11%	-13%	-22%	-48%
Conventional orchards and citrus groves – potash fertilizers	-16%	-34%	-22%	-48%
Organic orchards and citrus groves – potash fertilizers	26%	46%	-22%	-48%
Conventional field horticulture – potash fertilizers	-16%	-34%	-22%	-48%
Conventional greenhouse horticulture – potash fertilizers	-8%	-34%	-22%	-48%
Organic field horticulture – potash fertilizers	-8%	6%	-22%	-48%
Conventional olive growing – potash fertilizers	14%	31%	-25%	-49%
Organic olive growing – potash fertilizers	14%	31%	20%	43%
Conventional viticulture – potash fertilizers	26%	36%	-22%	-48%
Organic viticulture – potash fertilizers	-16%	-34%	-22%	-48%

Table 5.30 Variation of potash fertilizers use in FERT_10 and PEST_50 scenarios compared to BAU (tons).

	FERT_10		**PEST_50**	
	2025	**2030**	**2025**	**2030**
Conventional cereals – potash fertilizers	-6,2	-13,4	-8,7	-18,8
Organic cereals – potash fertilizers	-1,9	-4,2	3,8	7,9
Conventional forage – potash fertilizers	-0,5	-0,6	-1,0	-2,1
Conventional orchards and citrus groves – potash fertilizers	-50,8	-109,3	-71,1	-153,3
Organic orchards and citrus groves – potash fertilizers	28,5	49,8	-23,9	-51,6
Conventional field horticulture – potash fertilizers	-7,0	-15,0	-9,8	-21,0
Conventional greenhouse horticulture – potash fertilizers	-8,6	-35,8	-23,3	-50,2
Organic field horticulture – potash fertilizers	-4,5	3,4	-11,9	-25,6
Conventional olive growing – potash fertilizers	22,2	47,8	-38,1	-76,4
Organic olive growing – potash fertilizers	3,2	6,9	4,5	9,7
Conventional viticulture – potash fertilizers	9,8	13,4	-8,3	-17,8
Organic viticulture – potash fertilizers	-1,8	-4,0	-2,6	-5,6

Table 5.31 Share of potash fertilizers for the different crops in the FERT_10_PEST_50 and BAU scenarios.

	2025			**2030**		
	BAU	**FERT_10**	**PEST_50**	**BAU**	**FERT_10**	**PEST_50**
Conventional cereals	4%	4%	4%	4%	3%	4%
Organic cereals	2%	2%	3%	2%	2%	5%
Conventional forage	0,5%	0,4%	0,5%	0,5%	0,4%	0,4%
Conventional orchards and citrus groves	35%	30%	34%	35%	25%	32%
Organic orchards and citrus groves	12%	15%	12%	12%	18%	11%
Conventional field horticulture	5%	4%	5%	5%	3%	4%
Conventional greenhouse horticulture	11%	11%	11%	11%	8%	11%

Organic field horticulture	6%	5%	6%	6%	7%	5%
Conventional olive growing	17%	20%	16%	17%	24%	16%
Organic olive growing	2%	3%	4%	2%	3%	6%
Conventional viticulture	4%	5%	4%	4%	6%	4%
Organic viticulture	1%	1%	1%	1%	1%	1%

As highlighted in Tables 5.29, 5.30 and 5.31 conventional orchards and citrus groves, while remaining those with the greatest weight in the use of potassium fertilizers (**30%** in 2025 and **25%** in 2030 for the FERT_10 scenario and **34%** in 2025 and **32%** to 2030 for the PEST_50 scenario), show a significant reduction in both FERT_10 (**-50.8 tons** in 2025 and **-109.3 tons** in 2030) and PEST_50 (**-71.1 tons** in 2025 and **-153.3 ton** in 2030).

In PEST_50 scenario potash fertilizers use increases only for organic cereals (**+22%** in 2025 and **+44%** in 2030) and organic olive growing (**+20%** in 2025 and **+43%** in 2030).

The 10% overimposed decrease in the use of fertilizers (FERT_10) induces a reduction in the use of the active substances for the protection of conventional crops as follows: **-4%** (**-25 tons**) in 2025, **-14%** (**-82 tons**) in 2030 and **-11%** (**-65 tons**) in 2060 (table 5.32).

Instead, it induces an increase in the use of active substances for the protection of organic crops, and in particular **+0.4 tons** (**+3%**) in 2025, **+1.7 tons** (**+16%**) in 2030 and +**2.2 tons** (**+20%**) in 2060.

In the PEST_50 scenario, the exogenous constraint also implies a reduction of active substances for plant protection in organic crops: **-2.4 tons** (**-18%**) in 2025, **-7.4 tons** (**-40%**) in 2030 and **-7.4 tons** (**–37%**) in 2060.

Tab. 5.32 Use of active substances by crop production for each scenario (tons).

		2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Conventional crop protection	BAU	780	612	593	590	588	585	582	579	576	574
	FERT_10	568	508	508	508	508	508	508	508	568	508
	PEST_50	780	612	459	306	306	306	306	306	306	306
Organic crop protection	BAU	9	12	11	11	11	11	11	11	11	11
	FERT_10	9	12	12	14	14	14	14	14	14	14
	PEST_50	9	12	9	7	7	7	7	7	7	7

As shown in Table 5.33 the use active substances for plant protection decreases in conventional crops (e.g. other arable crops, cereals, orchards fruits and citrus, field horticulture) as follows: **-16%** in 2025, **-34%** in 2030, **-31%** in 2060 in FERT_10; **-22%** in 2025, **-48%** in 2030 and **–46%** in 2060 in PEST_50, while in greenhouse horticulture it decreases **-8%** in 2025, **-34%** in 2030 and **-31%** in 2060.

In FERT_10 the use of active substances for plant protection in conventional olive growing and conventional permanent meadows and pasture increases **+14%** in 2025, **+31%** in 2030 and **+25%** in 2060. In PEST_50 scenario the use of active substances increases only for conventional permanent meadows and pasture (**+20%** in 2025, **+ 43%** in 2025 and **+37%** in 2060).

An opposite trend is shown by conventional viticulture, in which the increase is **+ 26%** in 2025, **+ 36%** in 2030 and **+ 43%** in 2060 in FERT_10, while in PEST_50 a decrease is shown with percentages similar to those of the other crops.

Tab. 5.33 Variations of the use active substances for plant protection in conventional crops for FERT_10 and PEST_50 scenarios compared to the BAU scenario.

	FERT_10			PEST_50		
	2025	**2030**	**2060**	**2025**	**2030**	**2060**
Other arable crops	-16%	-34%	-31%	-22%	-48%	-46%
Cereals	-16%	-34%	-31%	-22%	-48%	-46%
Orchards and citrus groves	-16%	-34%	-31%	-22%	-48%	-46%
Field horticulture	-16%	-34%	-31%	-22%	-48%	-46%
Greenhouse horticulture	-8%	-34%	-31%	-22%	-48%	-46%
Olive growing	14%	31%	25%	-25%	-49%	-51%
Viticulture	26%	36%	43%	-22%	-48%	-46%
Permanent meadows and pastures	14%	31%	25%	20%	43%	37%

In FERT_10, the use of active substances for plant protection shows different trends in the various organic crops (table 5.34). Other arable crops and viticulture show a decrease with similar percentages (**-16%** in 2025, **-34%** in 2030 and **-31%** in 2060). In addition, cereals show a decrease (**-11%** in 2025, **-24%** in 2030 and **-23%** in 2060). On the other hand, an increase is shown by orchards and citrus groves (**+26%** in 2025, **+46%** in 2030 and **+53%** in 2060) as well as olive growing (**+14%** in 2025, **+31%** in 2030 and **+25%** in 2060). Field horticulture shows a decrease in 2025 (**-8%**) and an increase in 2030 (+**6%)** and in 2060 (**+12%**).

In PEST_50 other arable crops, orchards and citrus groves, field horticulture and viticulture show similar reduction percentages (**-22%** in 2025, **-48%** in 2030 and **-46%** in 2060) while cereals and olive growing show an increase (respectively **+22%** in 2025,

+48% in 2030 and **+46%** in 2060 and **+20%** in 2025, **+43%** in 2030 and **+37%** in 2060).

Tab. 5.34 Variations of active substances for plant protection in organic crops: comparison between FERT_10 PEST_50 and BAU scenarios.

	FERT_10			PEST_50		
	2025	**2030**	**2060**	**2025**	**2030**	**2060**
Other arable crops	-16%	-34%	-31%	-22%	-48%	-46%
Cereals	-11%	-24%	-23%	22%	44%	46%
Orchards and citrus groves	26%	46%	53%	-22%	-48%	-46%
Field horticulture	-8%	6%	12%	-22%	-48%	-46%
Olive growing	14%	31%	25%	20%	43%	37%
Viticulture	-16%	-34%	-31%	-22%	-48%	-46%

As regards the environmental impacts, the exogenous policy constraints and the consequent optimised distribution of land use lead to a decrease in total CO_2 emissions. In FERT_10, the reduction compared to BAU is **5 ktons** in 2025, **11 ktons** in 2030 and **9 kton**s in 2060. In PEST_50 there is a higher reduction (**-8 ktons** in 2025, **-17 ktons** in 2030 and **-15 ktons** in 2060) (Figure 5.14).

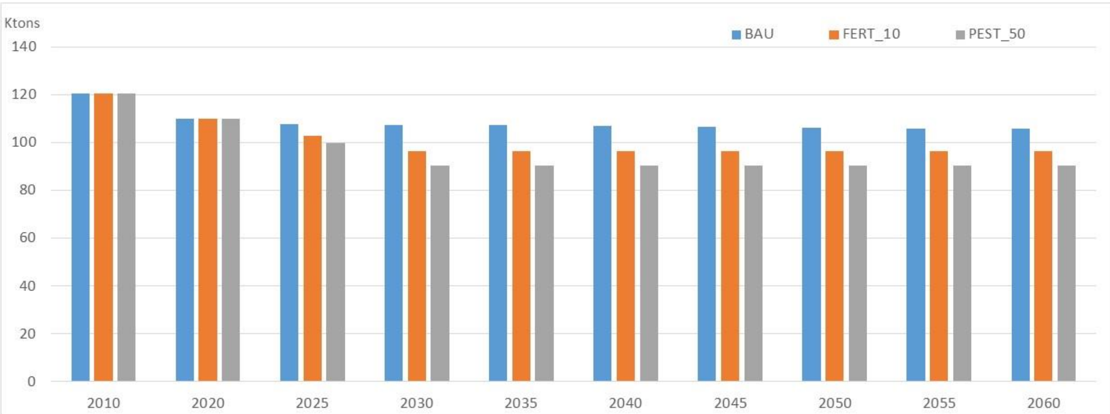

Figure 5.14 Total CO_2 emissions (ktons) in FERT_10, PEST_50 and BAU scenarios.

The decrease of CO_2 emissions is mainly due to the reduction of energy consumption in crop production and, to a lesser extent, to the reduction of energy consumption for irrigation. In the FERT_10 scenario, the reduction of CO_2 emissions due to the lower energy consumption of crop production is **-4.4 ktons** in 2025, **-9.6 ktons** in 2030 and **-8.2 ktons** in 2060, while that caused by the lower consumption of energy for irrigation is respectively **-0.8 ktons** in 2025, **-1.6 ktons** in 2030, **-1.2 ktons** in 2060.

In PEST_50 the reduction of CO_2 emissions increases both due to the lower energy consumption of crop production (**-6 ktons** in 2025, **-13.1 ktons** in 2030 and **-11.6 ktons** in 2060) and to the lower energy d for irrigation (**-1.9 ktons** in 2025, **-4.2 ktons** in 2030 and **-3.8 ktons** in 2060),

In PEST_50 there is a decrease in CO_2 emissions due to lower energy consumption both for crop production (**-6 ktons** in 2025, **-13.1 ktons** in 2030 and **-11.6 ktons** in 2060) and for irrigation (**-1.9 ktons** in 2025, **-4.2 ktons** in 2030 and **-3.8 ktons** in 2060). Furthermore, in percentage terms, in PEST_50 CO_2 emissions reduction due to lower energy consumption is higher than that observed in the FERT_10 scenario (respectively **-24%** and -**14%**). On the other hand, CO_2 emissions from livestock remain unchanged in both scenarios compared to BAU.

The slight decrease of CH_4 emissions is due to lower energy consumption. This share is negligible if compared to the total CH_4 emissions in which the main contributions are represented by wastewater management and enteric fermentation, which cannot decrease, as remediation interventions have not been foreseen.

Figure 5.15 shows the variations of N_2O emissions by scenario. N_2O emissions decrease in constrained scenarios mainly due to the lower use of nitrogen fertilizers in agricultural production and, only negligibly, to the lower energy consumption. In FERT_10, N_2O decreases by **-0.011 kton** in 2025, **-0.024 kton** in 2030 and **-0.021 kton** in 2060, while in PEST_50 it is **-0.017 kton** in 2025, **-0.037 kton** in 2030 and **-0.033 kton** in 2060.

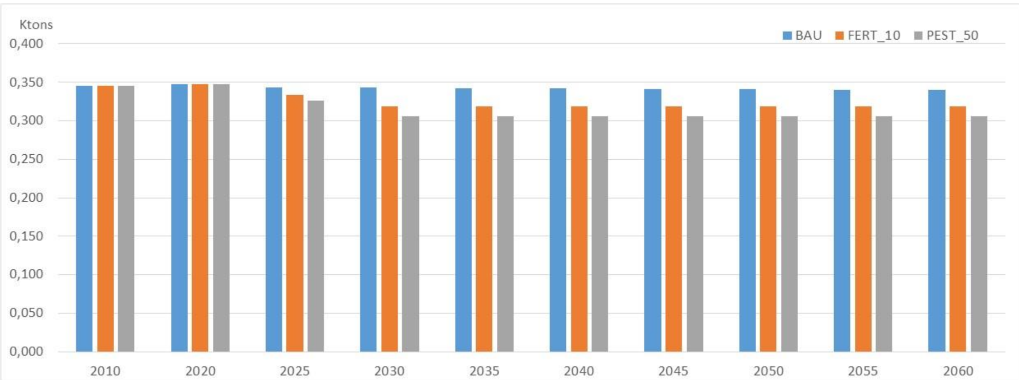

Figure 5.15 Total N_2O emissions (ktons) in FERT_10, PEST_50 and BAU scenarios.

The variation in waste production in the two constrained scenarios with respect to the BAU is due to the variation in crop production (Figure 5.16). Indeed, waste production decreased by **-57’101 tons** in 2025, **-124’959 tons** in 2030, **–109’237 tons** in 2060 in

FERT_10 scenario and **-62’847 tons** in 2025, **-136’700 tons** in 2030 and **-120’978 tons** in 2060 in PEST_50.

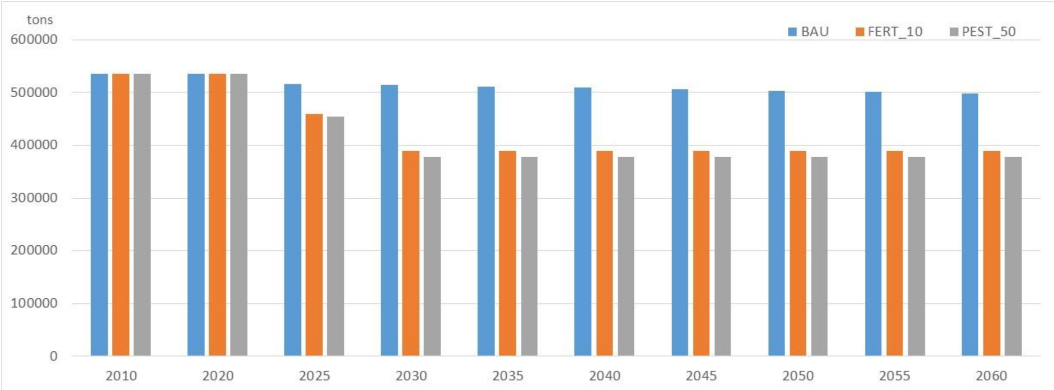

Fig. 5.16 Waste production from crop productions (tons) in FERT_10, PEST_50 and BAU scenarios.

As shown in Table 5.35, waste production from organic olive growing increases in both FERT_10 and PEST_50 scenarios, while that from organic cereals only in PEST_50, and that from organic orchards and citrus and conventional olive growing only in FERT_10. Waste production from conventional cereals shows the highest reduction in both FERT_10 and PEST_50 scenarios.

Table. 5.35 Variations of waste production (tons) in FERT_10 and PEST_50 compared to BAU scenario.

		2025	2030	2035	2040	2045	2050	2055	2060
Conventional other arable crops	FERT_10	-4318	-9293	-9088	-8882	-8677	-8471	-8265	-8060
	PEST_50	-6045	-13035	-12830	-12624	-12419	-12213	-12007	-11802
Organic other arable crops	FERT_10	-688	-1481	-1448	-1415	-1382	-1350	-1317	-1284
	PEST_50	-963	-2077	-2044	-2011	-1979	-1946	-1913	-1880
Conventional cereals	FERT_10	-46740	-100602	-98376	-96150	-93924	-91699	-89473	-87247
	PEST_50	-65436	-141109	-138884	-136658	-134432	-132207	-129981	-127755
Organic cereals	FERT_10	-11553	-25334	-25089	-24844	-24599	-24355	-24110	-23865
	PEST_50	23264	47651	47895	48140	48385	48630	48874	49119
Conventional orchard fruits and citrus	FERT_10	-2927	-6300	-6161	-6021	-5882	-5743	-5603	-5464
	PEST_50	-4098	-8837	-8698	-8558	-8419	-8279	-8140	-8001
Organic orchard fruits and citrus	FERT_10	1425	2491	2532	2572	2613	2654	2695	2735
	PEST_50	-1197	-2581	-2540	-2499	-2458	-2418	-2377	-2336
Conventional olive growing	FERT_10	5221	11237	10989	10740	10491	10243	9994	9746
	PEST_50	-8959	-17975	-18224	-18472	-18721	-18969	-19218	-19467
Organic olive growing	FERT_10	1776	3822	3738	3653	3569	3484	3399	3315
	PEST_50	2486	5361	5277	5192	5108	5023	4939	4854
Conventional viticulture	FERT_10	1288	1758	1795	1832	1869	1905	1942	1979
	PEST_50	-1082	-2333	-2296	-2259	-2223	-2186	-2149	-2112
Organic viticulture	FERT_10	-585	-1258	-1230	-1203	-1175	-1147	-1119	-1091
	PEST_50	-818	-1765	-1737	-1709	-1681	-1654	-1626	-1598

The optimal minimum cost solution that is obtained in compliance with the exogenous constraints on the use of fertilizers and pesticides of the FERT_10 and PEST_50 scenarios, implicates a reduction in total costs due to the selection of crops that require lower energy consumption and less water, with variable costs lower (Table 5.36).

Table. 5.36 Total costs (Meuro) for the policy scenarios compared to the BAU scenario.

	2010	**2020**	**2025**	**2030**	**2035**	**2040**	**2045**	**2050**	**2055**	**2060**
BAU	297	311	291	287	279	278	277	275	274	273
FERT_10	297	311	291	287	263	242	242	242	242	242
PEST_50	297	311	291	287	245	205	205	205	205	205

Indeed, comparing the total costs of FERT_10 and PEST_50 with BAU for the milestone years, the reduction for the FERT_10 scenario is **-6%** (**-16 MEuro**) in 2025, **-13%** (-36 MEuro) in 2030 and **-11%** (**-29 MEuro**) in 2060, while for PEST_50 it is **-13%** (**-34 MEuro**) in 2025, **-26%** (**-73 MEuro**) in 2030 and **-24%** (**-66 MEuro**) in 2060 (Figure 5.17).

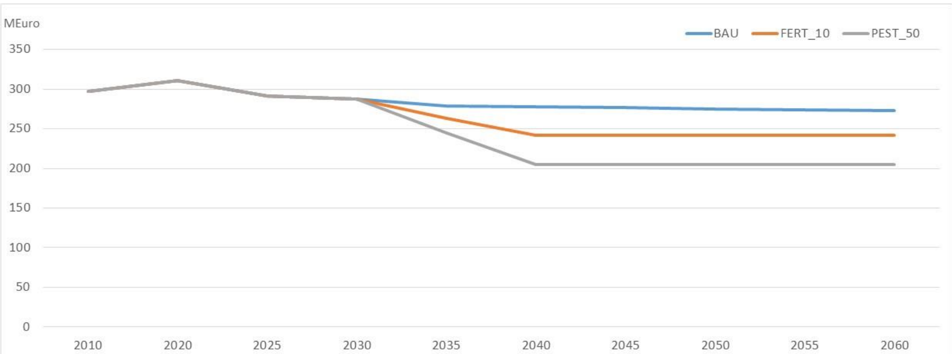

Fig. 5.17 Total costs (Meuro) for FERT_10, PEST_50 and BAU scenarios.

By observing in detail the costs for the various components of the agricultural sector and comparing the costs of FERT_10 and PEST_50 with those of the BAU scenario for the year 2030 (a milestone year characterized by the greatest variations), it is possible to select the crops that allow the greatest economic savings (Table 5.37).

In 2030, the reduction of irrigated crops leads to an economic saving of **14 MEuro** in FERT_10 and **36 MEuro** in PEST_50. Moreover, the variable costs of crop production decrease by **16 MEuro** in FERT_10 and by **22 MEuro** in PEST_50.

Table 5.37 Costs (MEuro) of the main categories for FERT_10 and PEST_50 compared to BAU scenario.

Unit (MEuro)		2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Enery consumption	BAU	42	34	33	33	33	33	33	33	33	32
	FERT_10	42	34	32	30	30	30	30	30	30	30
	PEST_50	42	34	31	28	28	28	28	28	28	28
Fertilizers	BAU	3	3	3	3	3	3	3	3	3	3
	FERT_10	3	3	3	3	3	3	3	3	3	3
	PEST_50	3	3	3	2	2	2	2	2	2	2
Crop protection	BAU	22	19	18	18	18	18	18	18	18	18
	FERT_10	22	19	18	17	17	17	17	17	17	17
	PEST_50	22	19	14	10	10	10	10	10	10	10
Water supply	BAU	74	89	85	84	84	83	83	82	82	81
	FERT_10	74	89	78	70	70	70	70	70	70	70
	PEST_50	74	89	68	48	48	48	48	48	48	48
Livestock	BAU	57	56	56	56	56	56	56	56	56	56
	FERT_10	57	56	56	56	56	56	56	56	56	56
	PEST_50	57	56	56	56	56	56	56	56	56	56
Crop production	BAU	87	73	70	70	70	69	69	68	68	68
	FERT_10	87	73	63	54	54	54	54	54	54	54
	PEST_50	87	73	60	48	48	48	48	48	48	48

A sensitivity analysis is also performed to investigate in-depth analysis the effects of reducing the use of fertilizers with reference to the targets of the Farm to Fork strategy.

To fully evaluate the response of the regional agricultural system to the standards of the Farm to Fork strategy, in addition to **FERT_10**, two other scenarios have been set up with reference to the targets of the strategy: **FERT_20** characterized by an exogenous reduction of 20% in the use of fertilizers by 2030 and without any restrictions on land use, **FERT_20_O25**, characterized by a 20% reduction in the use of fertilizers by 2030 and a use of land for organic farming no lesser than 25%. Table 5.38 summarises the analysed scenarios and the exogenous constraints.

Table 5.38 Overview of scenarios on fertiliser use.

Scenario	Reduction of fertilisers (%)	Availability of organic agricultural land
FERT_10	10%	Unconstrained
FERT_20	20%	Unconstrained
FERT_20_O25	20%	Minimum 25%

The optimization of the three scenarios with reference to the availability of organic agricultural land shows that in FERT_10 the achievement of a minimum share of 25% according to the F2F strategy is ensured without further limitations. In particular, the optimization of the FERT_10 scenario shows that by reducing the use of fertilizers by 10%, a **25.7 %** share of organic agricultural land in 2030 is achieved. On the other hand, In FERT_20 the 25% minimum target of organic agricultural area is not achieved endogenously and the share is **21.7 %**.

Table 5.39 shows the comparison of land use for the different crops in the three scenarios FERT_10, FERT_20 and FERT_20_O25 for the years 2025, 2030 and 2060, highlighting the remarkable differences in land use between the three.

Table 5.39 Land Use (ha) for agricultural production in the three scenarios with fertilizer reduction.

	2025			**2030**			**2060**		
	FERT_10	**FERT_20**	**FERT_20_O25**	**FERT_10**	**FERT_20**	**FERT_20_O25**	**FERT_10**	**FERT_20**	**FERT_20_O25**
Other arable crops – conventional	1474	2314	2314	1143	147	129	1143	147	129
Other arable crops – organic	162	337	337	125	16	14	125	16	14
Cereals - conventional	97474	40208	40208	75542	9747	8529	75542	9747	8529
Cereals - organic	32620	24775	24775	27854	2970	2599	27854	2970	2599
Forage - conventional	11281	4388	4388	10929	25530	6645	10929	25530	6645
Forage - organic	28313	35206	35206	28665	22825	36736	28665	22825	36736
Orchards and citrus groves - conventional	9536	3934	3934	7390	954	834	7390	954	834
Orchards and citrus groves - organic	3667	5104	5104	4217	4174	3315	4217	4174	3315
Horticulture in the field - conventional	4503	1858	1858	3490	9060	10616	3490	9060	10616
Greenhouse Horticulture - conventional	620	796	796	441	57	50	441	57	50
Horticulture in the field - organic	3341	1267	1267	3852	7369	7407	3852	7369	7407
Olive growing - conventional	26570	36977	36977	30556	37597	42186	30556	37597	42186
Olive growing - organic	6562	9132	9132	7546	10499	10553	7546	10499	10553
Permanent meadows and pastures - conventional	139590	194263	194263	160529	223344	224507	160529	223344	224507
Permanent meadows and pastures - organic	23117	26718	26718	26584	36987	37180	26584	36987	37180
Viticulture - conventional	1903	2649	2649	2037	127	111	2037	127	111
Viticulture - organic	744	1553	1553	577	74	65	577	74	65

In particular, the combined constraints support a shift to conventional permanent grassland and pasture that replaces conventional and organic cereals (Table 5.40). In fact, in 2025 conventional cereal land decreases by **-57’266 ha** both in FERT_20 and

FERT_20_O25 scenarios, **-65’795 ha** in the FERT_20 scenario and **-67’013 ha** in the FERT_20_O25 scenario in 2030.

On the other hand, conventional permanent meadows and pastures increase by **+54’673 ha** in 2025 both in the FERT_20 and FERT_20_O25 scenarios, while the variations in 2030 are **+62’816 ha** in the FERT_20 scenario and **+63’979 ha** in the FERT_20_O25 scenario.

As the land use constraint will come into effect by 2030, no changes are observed between the FERT_20 and FERT_20_O25 scenarios by 2025. However, the comparison of these two scenarios with FERT_10 highlights a reduction of conventional forage, conventional orchards and citrus groves, conventional and organic horticulture in field in addition to conventional and organic cereals.

The main differences between the FERT_20 and FERT_20_O25 scenarios occurring in 2030 are mainly due to forage cultivation. In fact, the 25% target set by the Farm to Fork strategy is achieved in FERT_20_O25 mainly through the increase of the land use for the cultivation of organic forage (**+8’071 ha**), which allows to fill the gap highlighted in the FERT_20 scenario.

Table 5.40 Land use variations (ha) for the different agricultural production compared to the FERT_10 scenario.

	2025			2030		
	FERT_10	**FERT_20**	**FERT_20_O25**	**FERT_10**	**FERT_20**	**FERT_20_O25**
Other arable crops – conventional	1474	840	840	1143	-995	-1’014
Other arable crops – organic	162	176	176	125	-109	-111
Cereals - conventional	97474	-57’266	-57’266	75542	-65’795	-67’013
Cereals - organic	32620	-7’845	-7’845	27854	-24’884	-25’255
Forage - conventional	11281	-6’893	-6’893	10929	14’601	-4’284
Forage - organic	28313	6’893	6’893	28665	-5’839	8’071
Orchards and citrus groves - conventional	9536	-5’602	-5’602	7390	-6’437	-6’556
orchards and citrus groves - organic	3667	1’436	1’436	4217	-44	-902
Horticulture in the field - conventional	4503	-2’646	-2’646	3490	5.570	7’126
Greenhouse Horticulture - conventional	620	175	175	441	-384	-391
Horticulture in the field - organic	3341	-2’074	-2’074	3852	3’517	3’555
Olive growing - conventional	26570	10’407	10’407	30556	7’041	11’630
Olive growing - organic	6562	2’570	2’570	7546	2’953	3’007
permanent meadows and pastures - conventional	139590	54’673	54’673	160529	62’816	63’979
permanent meadows and pastures - organic	23117	3’601	3’601	26584	10’403	10’595
Viticulture - conventional	1903	745	745	2037	-1’910	-1’926
Viticulture - organic	744	809	809	577	-502	-512

The variations in land use observed in FERT_20 and FERT_20_O25 are obviously reflected in energy, water and pesticides consumption. A **14%** decrease of diesel consumption is observed in FERT_20 and **15%** in FERT_20_O25 between 2030 and 2060 (Table 5.41). This trend is due to the lower consumption for crop production, espectively **-0.19 PJ** in FERT_20 and **-0.21 PJ** in FERT_20_O25.

Table 5.41 Diesel consumption (PJ) in the analysed scenarios.

Scenarios		2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
FERT_10	Crop production	1.34	1.26	1.18	1.10	1.10	1.10	1.10	1.10	1.10	1.10
	Livestock	0.22	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
	Irrigation	0.18	0.13	0.12	0.10	0.10	0.10	0.10	0.10	0.10	0.10
	Total	**1.74**	**1.59**	**1.48**	**1.39**	**1.39**	**1.39**	**1.39**	**1.39**	**1.39**	**1.39**
FERT_20	Crop production	1.34	1.26	0.98	0.92	0.92	0.92	0.92	0.92	0.92	0.92
	Livestock	0.22	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
	Irrigation	0.18	0.13	0.07	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	Total	**1.74**	**1.59**	**1.24**	**1.20**	**1.20**	**1.20**	**1.20**	**1.20**	**1.20**	**1.20**
FERT_20_O25	Crop production	1.34	1.26	0.98	0.90	0.90	0.90	0.90	0.90	0.90	0.90
	Livestock	0.22	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19
	Irrigation	0.18	0.13	0.07	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	Total	**1.74**	**1.59**	**1.24**	**1.18**	**1.18**	**1.18**	**1.18**	**1.18**	**1.18**	**1.18**

Figure 5.18 shows the trend in irrigation water consumption in the three scenarios. In FERT_10, water consumption for irrigation is always higher than in the FERT_20 and FERT_20_O25 scenarios. In 2025 there is a strong reduction of irrigation water (**-31’815’286 m^3**) both in FERT_20 and in FERT_20_O25, mainly due to the reduction in the demand for irrigation water from conventional orchards and citrus groves (**41’867’048 m^3** in FERT_10 and **17’270’158 m^3** in the FERT_20 and FERT_20_O25 scenarios).

In 2030, an increase of irrigation water in both the FERT_20 and FERT_20_O25scenarios is shown, due to an increase in availability of land use for conventional and organic horticulture in field. In particular, the consumptions estimated by the model for conventional horticulture are **9’646’305 m^3** in FERT_10, **25’041’782 m^3** in FERT_20, **29’342’978 m^3** in FERT_20_O25 for conventional horticulture in field and **10’393’697 m^3** in FERT_10, **19’881’454 m^3** in FERT_20, **19’985’003 m^3** in FERT_20_O25 for organic horticulture in the field.

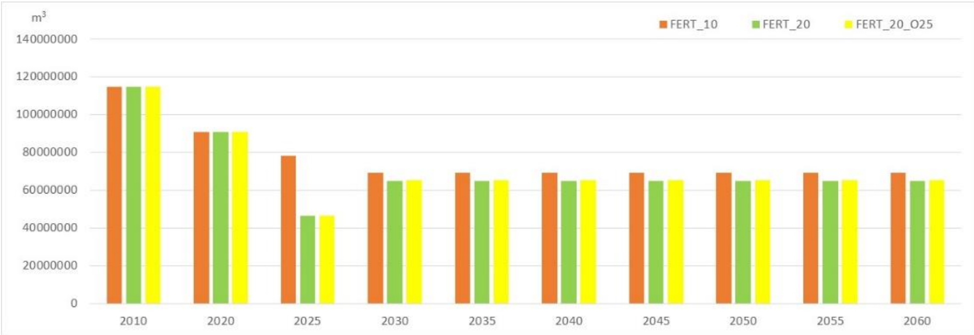

Figure 5.18 Irrigation water consumptions (m^3) in FERT_10, FERT_20 and FERT_20_O25 scenarios.

Compared to FERT_10, the use of active substances for plant protection in conventional crops decreases by **-230 tons** in FERT_20 and **-203 tons** in FERT_20_O25 (Figure 5.19).

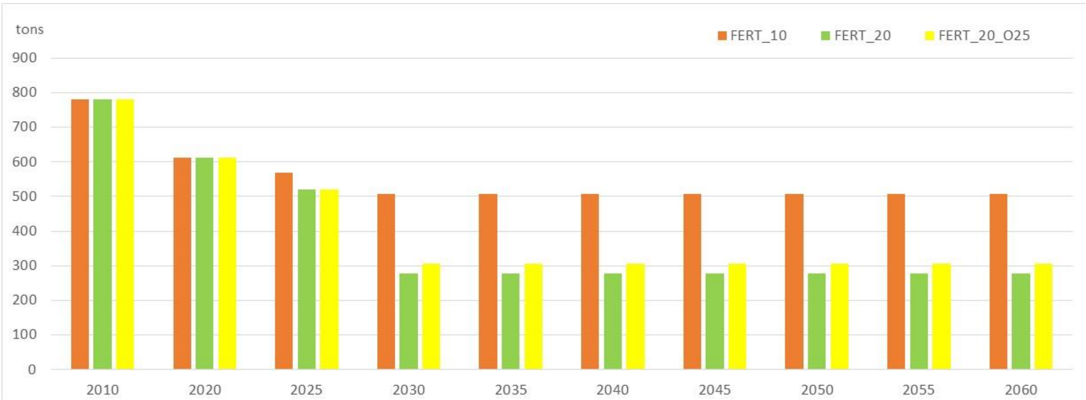

Figure 5.19 Active substances for plant protection - Conventional crops (tons) in FERT_10, FERT_20 and FERT_20_O25 scenarios.

Table 5.42 highlights the contribution by crop in conventional agriculture. The highest reductions are due to the decrease in the use of active substances for the protection of conventional orchards and citrus groves (**136.8 tons** in FERT_10, **17.7 tons** in FERT_20, **15.4 tons** in FERT_20_O25) and for the protection of conventional viticulture (**83.3 tons** in FERT_10, **5.2 tons** in FERT_20 scenario, **4.5 tons** in FERT_20_O25).

Tab. 5.42 Use of active substances for conventional crop protection (tons) in FERT_10, FERT_20 and FERT_20_025 scenarios.

		2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Conventional other arable crops	FERT_10	0.6	0.9	0.7	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	FERT_20	0.6	0.9	1.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
	FERT_20_O25	0.6	0.9	1.2	0.1	0.1	0.1	0.1	0.1	0.1	0.1
Conventional cereals	FERT_10	82.6	82.7	66.2	51.3	51.3	51.3	51.3	51.3	513	51.3
	FERT_20	82.6	82.7	27.3	6.6	6.6	6.6	6.6	6.6	6.6	6.6
	FERT_20_O25	82.6	82.7	27.3	5.8	5.8	5.8	5.8	5.8	5.8	5.8
Conventional orchards and citrus groves	FERT_10	287.9	220.7	176.5	136.,8	136.8	136.8	136.8	136.8	136.8	136.8
	FERT_20	287.9	220.7	72.8	17.7	17.7	17.7	17.7	17.7	17.7	17.7
	FERT_20_O25	287.9	220.7	72.8	15.4	15.4	15.4	15.4	15.4	15.4	15.4
Conventional horticulture in field	FERT_10	56.6	30.9	24.7	19.2	19.2	19.2	19.2	19.2	19.2	19.2
	FERT_20	56.6	30.9	10.2	49.8	49.8	49.8	49.8	49.8	49.8	49.8
	FERT_20_O25	56.6	30.9	10.2	58.3	58.3	58.3	58.3	58.3	58.3	58.3
Conventional greenhouse horticulture	FERT_10	106.0	99.7	87.0	61.8	61.8	61.8	61.8	61.8	61.8	61.8
	FERT_20	106.0	99.7	111.7	8.0	8.0	8.0	8.0	8.0	8.0	8.0
	FERT_20_O25	106.0	99.7	111.7	7.0	7.0	7.0	7.0	7.0	7.0	7.0
Conventional olive growing	FERT_10	139.4	112.2	134.6	154.8	154.8	154.8	154.8	154.8	154.8	154.8
	FERT_20	139.4	112.2	187.4	190.5	190.5	190.5	190.5	190.5	190.5	190.5
	FERT_20_O25	139.4	112.2	187.4	213.8	213.8	213.8	213.8	213.8	213.8	213.8
Conventional permanent meadows and pastures	FERT_10	0.4	0.4	0.5	0.6	0.6	0.6	0.6	0.6	0.6	0.6
	FERT_20	0.4	0.4	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	FERT_20_O25	0.4	0.4	0.7	0.8	0.8	0.8	0.8	0.8	0.8	0.8
Conventional viticulture	FERT_10	106.5	64.9	77.9	83.3	83.3	83.3	83.3	83.3	83.3	83.3
	FERT_20	106.5	64.9	108.3	5.2	5.2	5.2	5.2	5.2	5.2	5.2
	FERT_20_O25	106.5	64.9	108.3	4.5	4.5	4.5	4.5	4.5	4.5	4.5

On the other hand, the use of active substances for organic crops protection in FERT_20 and FERT_20_O25 is always higher than the values of the FERT_10 scenario (Figure 5.20). In FERT_20 the consumption is **17 tons** (**+4 tons** respect to FERT_10), while the consumption in FERT_20_O25 is **16 tons** (+**3 tons** more than FERT_10).

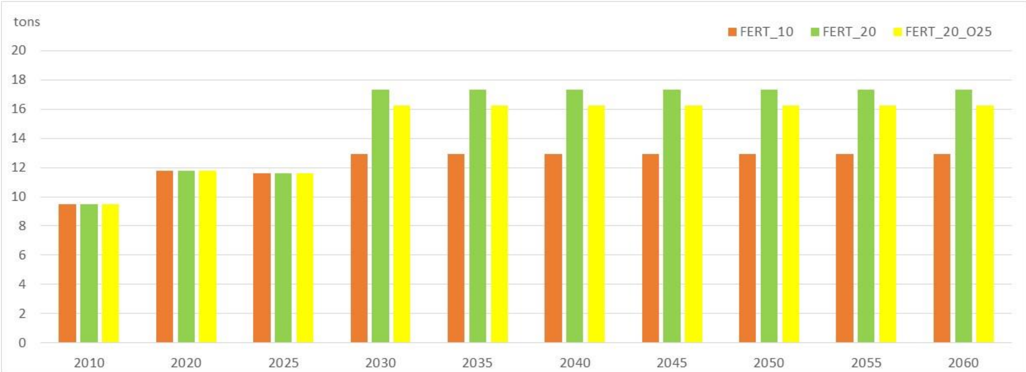

Fig. 5.20 Active substances for organic crop protection (tons) in FERT_10, FERT_20 and FERT_20_025 scenarios.

Table 5.43 shows that the greatest differences in the use of active substances for the protection of organic crops are found in open field horticulture (**5.65 tons** in FERT_10, **10.81 tons** in FERT_20 and **10.87 tons** in FERT_20_O25). For orchards and citrus groves, the greatest differences are found in FERT_20 and FERT_20_O25 scenarios (**5.37 tons** in FERT_20 and **4.27 tons** in FERT_20_O25).

Tab. 5.43 Use of active substances for organic crop protection (tons) in FERT_10, FERT_20 and FERT_20_O25 scenarios.

		2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Organic other arable crops	FERT_10	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
	FERT_20	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	FERT_20_O25	0.02	0.01	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Organic cereals	FERT_10	0.44	0.49	0.43	0.37	0.37	0.37	0.37	0.37	0.37	0.37
	FERT_20	0.44	0.49	0.33	0.04	0.04	0.04	0.04	0.04	0.04	0.04
	FERT_20_O25	0.44	0.49	0.33	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Organic orchards and citrus groves	FERT_10	5.37	3.93	4.72	5.43	5.43	5.43	5.43	5.43	5.43	5.43
	FERT_20	5.37	3.93	6.57	5.37	5.37	5.37	5.37	5.37	5.37	5.37
	FERT_20_O25	5.37	3.93	6.57	4.27	4.27	4.27	4.27	4.27	4.27	4.27
Organic horticulture in field	FERT_10	2.70	5.63	4.90	5.65	5.65	5.65	5.65	5.65	5.65	5.65
	FERT_20	2.70	5.63	1.86	1.81	1.81	1.,81	1.,81	1.,81	1.,81	1.,81
	FERT_20_O25	2.70	5.63	1.86	1.87	1.87	1.,87	1.,87	1.,87	1.,87	1.,87
Organic olive growing	FERT_10	0.38	0.52	0.62	0.72	0.72	0.72	0.72	0.72	0.72	0.72
	FERT_20	0.38	0.52	0.87	1.00	1.00	1.00	1.00	1.00	1.00	1.00
	FERT_20_O25	0.38	0.52	0.87	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Organic viticulture	FERT_10	0.55	1.18	0.94	0.73	0.73	0.73	0.73	0.73	0.73	0.73
	FERT_20	0.55	1.18	1.97	0.09	0.09	0.09	0.09	0.09	0.09	0.09
	FERT_20_O25	0.55	1.18	1.97	0.08	0.08	0.08	0.08	0.08	0.08	0.08

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Table 5.44 shows the variations in the consumption of nitrogen fertilizers between FERT_10, FERT_20 and FERT_20_O25 scenarios in 2030. In the latter two scenarios, conventional and organic other arable crops, conventional and organic cereals, conventional and organic orchards and citrus groves, conventional and organic viticulture, and conventional greenhouse horticulture all show a reduction in the consumption of nitrogen fertilizer compared to the FERT_10 scenario.

The consumption of nitrogen fertilizers for conventional cereals decreases by **3'262 tons** in FERT_20 and by **3'323 tons** in FERT_O25. On the other hand, conventional and organic horticulture in fields, conventional and organic olive growing and conventional permanent meadows and pastures show an increase in their consumption. In particular, the consumption of nitrogen fertilizers for conventional permanent grassland and pastures increases by **+ 1'729 tons** in the FERT_20 scenario and by **+ 1'761 tons** in the FERT_20_O25 scenario.

As concerns conventional and organic forage, there is an increase of **580 tons** in FERT_20 compared to FERT_10 and a decrease of **170 tons** in FERT_20_O25. On the other hand, organic forage decreases by **249 tons** in FERT_20 and increases by **344 tons** in the FERT_20_O25 scenario.

Tab. 5.44 Variation of nitrogen fertilizers (tons) in the FERT_20 and FERT_20_025 scenarios compared to FERT_10 scenario (year 2030).

	FERT_20	**FERT_20_O25**
Conventional other arable crops – nitrogen fertilizers	-290	-295
Organic other arable crops – nitrogen fertilizers	-71	-72
Conventional cereals – nitrogen fertilizers	-3.262	-3.323
Organic cereals – nitrogen fertilizers	-1.226	-1.244
Conventional forage – nitrogen fertilizers	580	-170
Organic forage – nitrogen fertilizers	-249	344
Conventional orchards and citrus groves – nitrogen fertilizers	-460	-469
Organic orchards and citrus groves – nitrogen fertilizers	-3	-64
Conventional horticulture in fields – nitrogen fertilizers	184	235
Conventional greenhouse horticulture – nitrogen fertilizers	-157	-160
Organic horticulture in fields – nitrogen fertilizers	62	62
Conventional olive growing – nitrogen fertilizers	356	588
Organic olive growing – nitrogen fertilizers	133	136
Conventional permanent meadows and pasture – nitrogen fertilizers	1.729	1.761
Conventional viticulture – nitrogen fertilizers	-265	-267
Organic viticulture – nitrogen fertilizers	-69	-70

Potash fertilizers show very similar trends in FERT_20 and FERT_20_O25 scenarios compared to FERT_10 (table 5.45). Only conventional forage increases **+5 ton** in FERT_20 and reduces of **-2 ton** in FERT_20_O25. All the other crops show very similar trends between the two scenarios, with the exception of conventional field horticulture that increases **+46 tons** in FERT_20 and **+59 tons** in FERT_20_O25, and conventional olive growing (**+47 tons** in FERT_20 and **+78 tons** in FERT_20_O25).

Conventional and organic cereals, conventional and organic orchards and citrus groves, conventional greenhouse horticulture, conventional and organic viticulture show a reduction in the consumption of potash fertilizers in both scenarios compared to FERT_10, while consumption of potash fertilizers increases in conventional and organic horticulture in the field and conventional and organic olive growing in both scenarios compared to FERT_10.

Tab. 5.45 Variation of potash fertilizers (tons) in absolute value in two scenarios compared to FERT_10 scenario (year 2030).

	FERT_20	FERT_20_O25
Conventional cereals – potash fertilizers	-22	-23
Organic cereals – potash fertilizers	-12	-12
Conventional forage – potash fertilizers	5	-2
Conventional orchards and citrus groves – potash fertilizers	-183	-186
Organic orchards and citrus groves – potash fertilizers	-2	-34
Conventional horticulture in fields – potash fertilizers	46	59
Conventional greenhouse horticulture – potash fertilizers	-60	-61
Organic horticulture in fields – potash fertilizers	52	52
Conventional olive growing – potash fertilizers	47	78
Organic olive growing – potash fertilizers	12	12
Conventional viticulture – potash fertilizers	-47	-48
Organic viticulture – potash fertilizers	-7	-7

The trend in the consumption of phosphorus fertilizers is very similar to that of potash fertilizers (table 5.46). Conventional forage consumption shows an increase of **+ 16 tons** in FERT_20 and a decrease of **-5 tons** in FERT_20_O25. Conventional field horticulture consumption increases **+ 46 tons** in FERT_20 and **+59 tons** in FERT_20_O25 while conventional olive growing consumption increases **+47 tons** in FERT_20 and **+78 tons** in FERT_20_O25. Table 5.45 reports the values recorded in the two scenarios compared to FERT_10 for the year 2030.

Tab. 5.46 Variation of phosphorus fertilizers (tons) in the FERT_20 and FERT_20_O25 scenarios compared to FERT_10 (year 2030).

Unit (tons)	FERT_20	FERT_20_O25
Conventional other arable crops – phosphorus fertilizers	-3	-3
Conventional cereals – phosphorus fertilizers	-87	-88
Organic cereals – phosphorus fertilizers	-8	-8
Conventional forage – phosphorus fertilizers	16	-5
Conventional orchards and citrus groves – phosphorus fertilizers	-127	-129
Organic orchards and citrus groves – phosphorus fertilizers	-1	-25
Conventional horticulture in fields – phosphorus fertilizers	45	57
Conventional greenhouse horticulture – phosphorus fertilizers	-44	-45
Organic horticulture in fields – phosphorus fertilizers	34	34
Conventional olive growing – phosphorus fertilizers	57	94
Organic olive growing – phosphorus fertilizers	10	10
Conventional viticulture – phosphorus fertilizers	-51	-52
Organic viticulture – phosphorus fertilizers	-10	-10

The decrease in energy consumption observed in the two scenarios FERT_20 and FERT_20_O25 leads to a reduction in total CO_2 emissions (Figure 5.21). From 2030 onwards, CO_2 emissions decrease by **12 ktons** in FERT_20 and by **14 ktons** in FERT_20_O25.

In both scenarios, the decrease of CO_2 emissions compared to FERT_10 is attributable for **94%** to the lower consumption of diesel for agricultural crops and for **6%** to the lower consumption of diesel for irrigation.

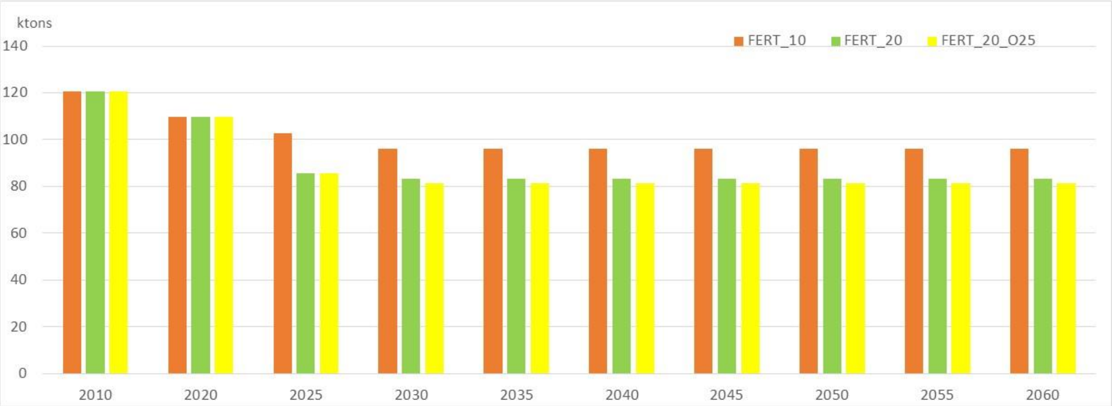

Fig. 5.21 Total CO_2 emissions (ktons) FERT_10, FERT_20 and FERT_20_025 scenarios.

CH_4 emissions do not show significant variations as they are almost entirely produced by the livestock sector. N_2O emissions decrease by **16%** (**-0.05 kton**) both in FERT_20 and in FERT_20_O25 compared to the FERT_10 scenario following the lower use of nitrogen fertilizers.

Waste production also decreases in FERT_20 and FERT_20_O25 compared to FERT_10 (Table 5.47). The changes detected are constant over the period 2030-2060 with values of FERT_20 slightly lower than those of FERT_20_O25. The greatest reduction occurs for conventional cereals (**-168’263 tons** in the FERT_20 scenario and **-171’379 tons** in the FERT_20_O25 scenario).

The observed variations are constant over the period 2030-2060, with values of FERT_20 slightly lower than those of FERT_20_O25. The greatest reduction occurs for conventional cereals (**-168’263 tons** in FERT_20 and **-171’379 tons** in FERT_20_O25).

The highest percentage decrease occurs for conventional viticulture (**-94%** in the FERT_20 scenario and **-95%** in the FERT_20_O25 scenario). On the other hand, conventional and organic olive growing show an increase of **11’067 tons** (**+23%**) and **+ 6’393 tons** (**+39%**) respectively in the FERT_20 scenario and of **18’281 tons** (**+ 38%**) and **6’511 tons** (**+ 40%**) in the FERT_20_O25 scenario.

Conventional viticulture shows the highest percentage decrease (**-94%** in FERT_20 and **-95%** in FERT_20_O25). On the other hand, conventional and organic olive growing show an increase of 23% (11’067 tons) and 39% (+ 6’393 tons) in FERT_20, + 38% (18’281 tons) and + 40% (6’511 tons) in FERT_20_O25.

Table 5.47 Waste production (tons) variations: comparison of FERT_20 and FERT_20_O25 scenarios with FERT_10 scenario.

	FERT_20	FERT_20	FERT_20_O25	FERT_20_O25
Conventional other arable crops	-15’544	-87%	-15’832	-89%
Organic other arable crops	-2’476	-87%	-2’522	-89%
Conventional cereals	-168’263	-87%	-171’379	-89%
Organic cereals	-73’239	-89%	-74’332	-91%
Conventional orchard fruits and citrus	-10’537	-87%	-10’733	-89%
Organic orchard fruits and citrus	-81	-1%	-1’683	-21%
Conventional olive growing	11’067	23%	18’281	38%
Organic olive growing	6’393	39%	6’511	40%
Conventional viticulture	-6’203	-94%	-6’255	-95%
Organic viticulture	-2’105	-87%	-2’144	-89%

The increase in the restriction on the consumption of fertilizers from 10% to 20% leads to a reduction of the total annual cost of **6%** in the FERT_20 scenario and **5%** in the FERT_20_O25 scenario, respectively, compared to the FERT_10 scenario.

Reducing the consumption of fertilizers by 20% (target of the F2F strategy) leads to a **6%** reduction of the total annual cost in FERT_20 and **5%** in FERT_20_O25 compared respectively to FERT_10 (Figure 5.22).

Figure 5.22 Trends of total system costs scenarios with reduction of fertilizer use in FERT_10, FERT_20 and FERT_20_025 scenarios.

Table 5.48 shows the total annual costs for the main crop categories considered in the two scenarios FERT_20 and FERT_20_O25. The annual cost of energy consumption in the two scenarios is the same (**26 MEuro**) and decreases by **4 MEuro** compared to FERT_10. The same trend is found for the water supply, with an annual cost of **66 MEuro** and a decrease of 4 **MEuro** compared to FERT_10.

The annual costs for crop protection are lower than those of the FERT_10 scenario (**12 MEuro** in FERT_20 and **13 MEuro** in FERT_20_O25 compared to **17 MEuro** of the FERT_10 scenario). Finally, the annual production costs of crops in the FERT_20_O25 scenario are the same as those in the FERT_10 scenario (**54 MEuro**), while in the FERT_20 scenario they are **3%** lower.

Table. 5.48 Annual costs (MEuro) of the main crop categories: FERT_10, FERT_20 and FERT_20_O25 scenarios.

		2010	2020	2025	2030	2035	2040	2045	2050	2055	2060
Energy consumption	FERT_10	42	34	32	30	30	30	30	30	30	30
	FERT_20	42	34	27	26	26	26	26	26	26	26
	FERT_20_O25	42	34	27	26	26	26	26	26	26	26
Fertilizers	FERT_10	3	3	3	3	3	3	3	3	3	3
	FERT_20	3	3	3	2	2	2	2	2	2	2
	FERT_20_O25	3	3	3	2	2	2	2	2	2	2
Crop protection	FERT_10	22	19	18	17	17	17	17	17	17	17
	FERT_20	22	19	17	12	12	12	12	12	12	12
	FERT_20_O25	22	19	17	13	13	13	13	13	13	13
Water supply	FERT_10	74	89	78	70	70	70	70	70	70	70
	FERT_20	74	89	49	66	66	66	66	66	66	66
	FERT_20_O25	74	89	49	66	66	66	66	66	66	66
Livestock	FERT_10	57	56	56	56	56	56	56	56	56	56
	FERT_20	57	56	56	56	56	56	56	56	56	56
	FERT_20_O25	57	56	56	56	56	56	56	56	56	56
Crop production	FERT_10	87	73	63	54	54	54	54	54	54	54
	FERT_20	87	73	47	52	52	52	52	52	52	52
	FERT_20_O25	87	73	47	54	54	54	54	54	54	54

5.3 Climate scenarios analysis: main results

The climate scenario (CLIM) is set up to evaluate the response of the agricultural system of Basilicata to the reduction of agricultural yields caused by a temperature increase of 2 degrees. Table 5.49 shows the crop productions from 2040 to 2060.

Table5.49 Crop productions (tons).

Unit (tons)	2040	2045	2050	2055	2060
Conventional other arable crops	3390	3364	3338	3312	3286
Organic other arable crops	372	369	366	363	360
Conventional cereals	244329	242449	240570	238690	236811
Organic cereals	85213	85716	86220	86723	87227
Conventional forage	130421	129418	128414	127411	126408
Organic forage	287802	288805	289808	290812	291815
Conventional orchards and citrus groves	149429	148280	147130	145981	144832
Organic orchards and citrus groves	38310	38015	37721	37426	37131
Conventional field horticulture	149885	148732	147579	146426	145273
Conventional greenhouse horticulture	19530	19379	19229	19079	18929
Organic field horticulture	102195	101409	100623	99837	99051

Conventional olive growing	23966	23782	23598	23413	23229
Organic olive growing	6829	6875	6920	6966	7011
Conventional permanent meadows and pastures	168502	169625	170749	171872	172995
Organic permanent meadows and pastures	27905	28091	28277	28463	28649
Conventional viticulture	18186	18046	17907	17767	17627
Organic viticulture	10664	10582	10500	10418	10336

In fact, in the CLIM scenario all agricultural productions show a decrease respect to the BAU scenario, except for conventional greenhouse horticulture, as shown in Table 5.50.

Table 5.50 Variations of crop productions (tons) for CLIM scenario compared to the BAU scenario.

	2040	2045	2050	2055	2060
Conventional other arable crops	-87	-86	-86	-85	-84
Organic other arable crops	-10	-9	-9	-9	-9
Conventional cereals	-61082	-60612	-60142	-59673	-59203
Organic cereals	-12764	-12036	-11308	-10580	-9852
Conventional forage	-11341	-11254	-11166	-11079	-10992
Organic forage	-25026	-25113	-25201	-25288	-25375
Conventional orchards and citrus groves	-26370	-26167	-25964	-25761	-25559
Organic orchards and citrus groves	-6761	-6709	-6657	-6605	-6553
Conventional field horticulture	-16654	-16526	-16398	-16270	-16141
Conventional greenhouse horticulture	0	0	0	0	0
Organic field horticulture	-11355	-11268	-11180	-11093	-11006
Conventional olive growing	-8567	-8968	-9370	-9771	-10172
Organic olive growing	-1205	-1213	-1221	-1229	-1237
Conventional permanent meadows and pastures	-18722	-18847	-18972	-19097	-19222
Organic permanent meadows and pastures	-3101	-3121	-3142	-3163	-3183
Conventional viticulture	-5432	-5391	-5349	-5307	-5265
Organic viticulture	-3185	-3161	-3136	-3112	-3087

Conventional cereals show the highest decrease in absolute value (**-61’082 tons** in 2040 and **-59’203 tons** in 2060), followed by conventional orchards and citrus groves (**-26’370 tons** in 2040 and **-25’559 tons** in 2060) and by organic forage (**-25’026 tons** in 2040 and **-25’375 tons** in 2060).

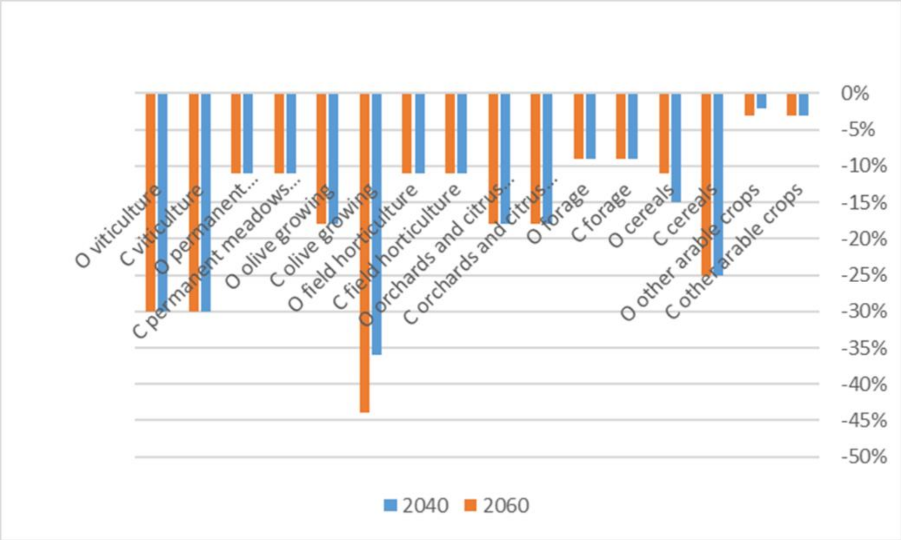

Figure 5.23 Variations of crop productions (%) for CLIM scenario compared to the BAU scenario.

The highest percentage decreases (Figure 5.23) are observed for conventional olive growing (**36%** in 2040 and **44%** in 2060), for conventional and organic viticulture (**-30%** in 2040 and in 2060) and for conventional cereals (**-25%** in 2040 and in 2060).

As concerns energy consumption, in the CLIM scenario total diesel consumption are almost identical to values observed in the BAU scenario (Table 5.51).

Table 5.51 Total diesel consumption (PJ) in BAU and CLIM scenarios.

	2040	2045	2050	2055	2060
BAU	1.54	1.54	1.53	1.53	1.52
CLIM	1.55	1.54	1.54	1.54	1.53

Diesel consumption per unit of product is **0.93 GJ/ton** in the CLIM scenario, while it is **0.81 GJ/ton** in the BAU scenario.

The use of fertilizers does not show significant variations compared to BAU (Table 5.52). The use of phosphate fertilizer decreases by **3%** in 2040 and by **4%** in 2060 compared to BAU.

Table 5.52 Total fertilizer consumption (tons) in BAU and CLIM scenarios.

Fertilizers	Scenarios	2040	2045	2050	2055	2060
Nitrogen	BAU	16385	16351	16318	16285	16252
	CLIM	16380	16347	16313	16280	16246
Potash	BAU	909	905	900	896	892
	CLIM	889	883	877	871	864
Phosphate	BAU	896	892	888	884	881
	CLIM	871	865	859	852	846

The use of active substances for crop protection decreases by **3%** in 2040 and **by 4%** in 2060 for conventional crops, while the variations are negligible for organic crops (Table 5.53).

Tab. 5.53 Use of active substances for crop protection for each scenario (tons) in BAU and CLIM scenarios.

		2040	**2045**	**2050**	**2055**	**2060**
Conventional crop protection	BAU	585	582	579	576	574
	CLIM	569	564	560	556	551
Organic crop protection	BAU	11.02	10.94	10.87	10.80	10.72
	CLIM	11.06	10.99	10.92	10.85	10.78

Small variations are also observed for total CO_2 emissions (Table 5.54), while CO_2 emissions per unit of product increase of **15%** in the period 2040 -2060 (**0.064** tons CO_2 per unit of product in the BAU scenario and **0.073** tons CO_2 per unit of product in the CLIM scenario).

Tab. 5.54 Total CO_2 emissions (ktons) in BAU and CLIM scenarios.

	2040	**2045**	**2050**	**2055**	**2060**
BAU	107	107	106	106	106
CLIM	107	107	107	106	106

An alternative scenario (CLIM_1) has been set up to evaluate under which conditions the regional agricultural system can produce the same quantities of products as the BAU scenario, taking into account the yield reductions caused by the average temperature increase of 2 degrees.

To ensure the same agricultural production taking into account the reduction in yield caused by climate change, about **60'000 hectares** (about **17%**) more are needed, divided as indicated in Table 5.55.

Tab. 5.55 Total land use (ha) in BAU and CLIM_1 scenarios.

	2040	**2045**	**2050**	**2055**	**2060**
BAU	391477	391477	391477	391477	391477
CLIM_1	457818	457690	457562	457434	457305

Figure 5.24 shows land use by crop estimated in the CLIM_1 scenario where conventional permanent meadows and pastures (**138'482 ha** in 2040 and **142'175 ha** in 2060) and conventional cereals are the most widespread crops (**141'424 ha** in 2040 and **137'072 ha** in 2060).

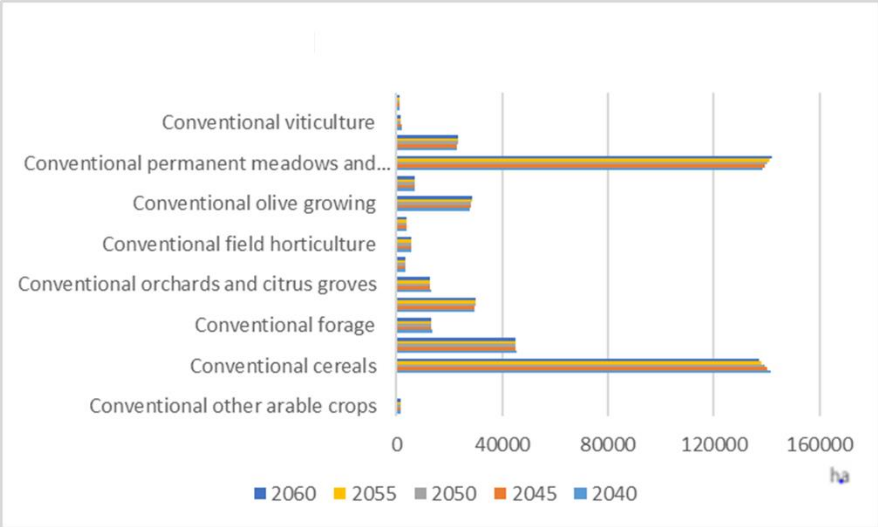

Figure 5.24 Land Use for agricultural production (Hectares by crop) – CLIM_1 scenario.

Figure 5.25 shows the land use percentage variations for each crop obtained in the CLIM_1 scenario compared to the BAU scenario.

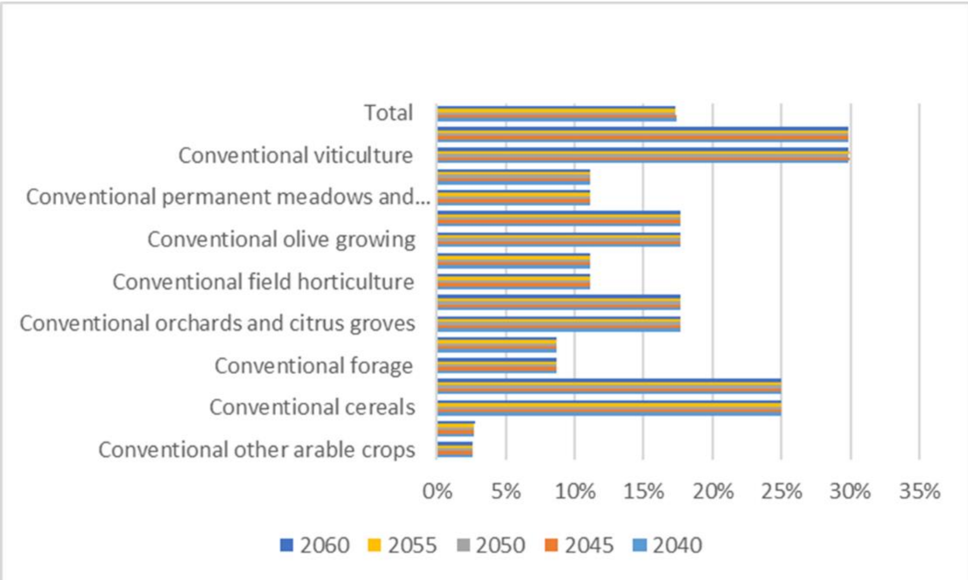

Figure 5.25 Variations of land use (%) in the CLIM_1 scenario.

The largest increase in hectares would be necessary for conventional cereals (**28’285 ha** in 2040 and **27’414 ha** in 2060) and conventional permanent meadows and pastures (**13’848 ha** in 2040 and **14’218 ha** in 2060).

Similarly, diesel consumption is expected to increase by approximately **15% -16%** (Table 5.56).

Table 5.56 Total diesel consumption (PJ) in BAU and CLIM_1 scenarios.

	2040	2045	2050	2055	2060
BAU	1.54	1.54	1.53	1.53	1.52
CLIM_1	1.78	1.78	1.77	1.76	1.76

Table 5.57 shows the quantities of the fertilizes used compared to the BAU scenario: nitrogen fertilizers should increase by **18%**, potash fertilizers by **16%** and phosphate fertilizers by **17%**.

Table 5.57 Use of fertilizers (tons) in BAU and CLIM_1 scenarios.

Fertilizers	Scenarios	2040	2045	2050	2055	2060
Nitrogen	BAU	16385	16351	16318	16285	16252
	CLIM_1	19331	19288	19245	19202	19159
Potash	BAU	909	905	900	896	892
	CLIM_1	1054	1050	1045	1040	1035
Phosphate	BAU	896	892	888	884	881
	CLIM_1	1052	1048	1043	1039	1034

The use of active substances for crop protection should increase by **17%** for conventional products and by **16%** for organic products (Table 5.58).

Table 5.58 Use of active substances for crop protection (tons) in BAU and CLIM_1 scenarios.

		2040	2045	2050	2055	2060
Conventional crop protection	BAU	585	582	579	576	574
	CLIM_1	683	679	676	673	670
Organic crop protection	BAU	11.02	10.94	10.87	10.80	10.72
	CLIM_1	12.8	12.7	12.6	12.5	12.4

Horticulture and orchards and citrus groves would need an increased supply of water for irrigation. For this reason, total irrigation water is expected to increase to **97.6 Mm^3** in 2040 (**84.5 Mm^3** in BAU) and to **94.6 Mm^3** in 2060 (**81.9 Mm^3** in BAU) (Table 5.59).

Tab. 5.59 Total irrigation water (Mm^3) in BAU and CLIM_1 scenarios.

	2040	**2045**	**2050**	**2055**	**2060**
BAU	84.5	83.8	83.2	82.5	81.9
CLIM_1	97.6	96.8	96.1	95.3	94.6

The higher consumption of diesel in the CLIM_1 scenario leads to an increase of about **15%** in CO_2 emissions (Table 5.60).

Table 5.60 Total CO_2 emissions (ktons) in BAU and CLIM_1 scenarios.

	2040	**2045**	**2050**	**2055**	**2060**
BAU	107	107	106	106	106
CLIM_1	123	123	123	122	122

The increased use of fertilizers and active ingredients for crop protection, diesel oil and irrigation water leads to an increase of **2%** in the total cost of the plant (**2'136 MEuro** against **2'089 MEuro** in the BAU scenario) and in the total annual costs of **7%** (Table 5.61).

Table 5.61 Total annual costs (MEuro) in BAU and CLIM_1 scenarios.

Unit (MEuro)	2040	2045	2050	2055	2060
BAU	275	274	273	272	271
CLIM_1	295	294	293	291	290

5.4 Discussion

The work carried out had the aim of contributing to progress in the analysis of complex energy systems with the ETSAP-TIMES methodology. To this issue, relevant examples were examined to set up a sectoral model aimed at investigating in depth the agricultural and forestry sectors with a supply-demand approach driven by land use.

A fundamental reference model for its development was the Irish TIMES (Chiodi, 2016), a national single region energy model, which extended the ETSAP-TIMES modeling approach to the representation of agriculture in order to provide insights into the dynamics and interactions between the energy and agricultural sectors while exploring the role of livestock emissions on GHGs reduction strategies in Ireland.

Another interesting study, conducted by Sehen and Blesl in Germany (2021), examined the interactions between water uses for energy, irrigation and energy crops, analyzing the interdependence of water use for irrigation and biomass demand, which should increase to meet climate goals.

Starting from this literature background, the TIMES Basilicata Land-WEF model has been outlined to go beyond the typical energy-driven approach by introducing land use as the main variable to model the agricultural system and highlight the consequences of climate change, policy objectives and other environmental constraints in terms of changes in land use, considering also the role of the forests as CO_2 absorbers.

To this issue new input variables were added to model the complexity of the agricultural system and the effects of the EU agricultural policies, among which fertilizers and active substances for crops protection. To fully assess the potential impacts of EU agricultural policies conventional and organic cultivation processes were also distinguished. Besides that, while the other models mentioned above were developed at a national scale, the TIMES Basilicata Land-WEF was designed as a local scale model to assess the role of the agricultural sector in the Basilicata region (Southern Italy). Therefore, it was developed as a single module to be further integrated in the TIMES-Basilicata energy model (Di Leo, 2015) in order to analyze in a circular economy perspective the whole regional system and the interrelations among the five macroeconomic sectors (agriculture, industry, residential, tertiary, transport) exploiting the synergies between the different components.

The scenario analysis allows highlighting the impact of different boundary conditions and the effects of agricultural policies (namely the Farm to Fork Strategy) in terms of resource uses and contribution to GHG emissions reduction as well as investigating the consequences of a reduced food productivity caused by climate change.

The optimal solutions identify a share of land use between conventional and organic cultivation around 25% over the entire time horizon in line with by the Farm to Fork strategy and a general increase of the agricultural area dedicated to permanent meadows and pastures. These results are in agreement with what reported in literature, which underlines how the EU agricultural policy mechanisms such as greening (Cortignani, 2018) as well as the phenomena of land abandonment (Schuh, 2020), which are determined by a complex of causes including biophysical, agricultural, structural, market, regional, institutional and political, can support such a change in the medium-long term.

In particular, the BaU scenario highlights that in a vision of economic optimum, less energy-intensive crops (requiring fewer processing steps and less use of fertilizers and substances for crop protection) and non-irrigated crops will be privileged, also leading to a decrease of CO_2 total emissions by approximately 4% in 2060 compared to 2020.

On the other hand, due to the effects of climate change, the agricultural system will experience a decrease in the total production of food and biomass for energy use (respectively about 5% and 7%).

The PEST_50 and FERT_20 scenarios, which implement the provisions of the Farm to Fork strategy, lead to significant changes in land use and resources respect to BaU.

In particular, land use for conventional cereals decreases both in the FERT_10 and in the PEST_50 scenarios compared to the BAU, in line with the findings of Barreiro-Hurle, (2021) which explore the potential effects of Farm to Fork and Biodiversity strategies targets on EU agriculture and the achievement of climate targets, highlighting the huge impact of climate change on cereal production in the Mediterranean area, with an estimated reduction of yield production between 20% and 40%.

The results of the assessment of EU agricultural policy are also in line with the conclusions of other studies for the evaluation of the sustainability and potential effects of the EU Green Deal strategies in the agricultural sector (Barreiro, 2021; Beckman, 2020; Bremmer, 2021). According to these studies, in fact, the implementation of the Farm to Fork strategy, while contributing to the sustainability of the agricultural system and the achievement of climate neutrality by 2050 through the reduction of GHG emissions of other pollutants and harmful substances, could have the main effect collateral a significant reduction in agricultural production, with the consequent loss of domestic market shares by European producers in favor of those of other countries with less stringent production standards. As a result, this could undermine these efforts globally, leading to increased greenhouse gas emissions and unsustainable land use in areas where agricultural production is relocated, resulting in food insecurity of 22 million people (Ferrero, 2021).

Regarding the preliminary results of the analysis of a climate scenario (CLIM) that examines the average loss of crop yield caused by an average temperature increase of 2° C, it can be noted that all categories show a significant decrease in agricultural production, with the exception of conventional greenhouse horticulture. The most relevant decrease is observed for conventional olive growing (-36% in 2040 and -44% in 2060), conventional and organic viticulture (-30% both in 2040 and in 2060) and for conventional cereals (-25% in 2040 and 2060). On the other hand, the decrease in agricultural yields for the same hectares leads to an increase in fuel consumption per unit of product and the consequent increase in CO_2 emissions per unit of product (+ 15% on average).

The sensitivity analysis carried out subsequently (CLIM_1 scenario), aimed at assessing under which conditions the regional agricultural system could produce the same quantities of food as the BAU scenario, shows that, taking into account the reduction in agricultural yield resulting if the average temperature increases at 2° C, about 60,000 hectares more (about 17%) would be needed to guarantee the same agricultural production.

The analysis of climate scenario points out the limits of the TIMES Basilicata Land WEF model. In fact, yield reduction is not able to explain the complexity of the climate change and its potential effects on the agricultural sector. In addition to this, it is necessary to investigate the role of soil degradation and the consequences of a drastic reduction in water availability by including in the model adequate mitigation and adaptation measures both in relation to possible technological options and nature based solutions (NBS).

References Chapter V

Barreiro-Hurle, J., Bogonos, M., Himics, M., Hristov, J., Pérez-Domiguez, I., Sahoo, A., Salputra, G., Weiss, F., Baldoni, E., Elleby, C. (2021). Modelling environmental and climate ambition in the agricultural sector with the CAPRI model. Exploring the potential effects of selected Farm to Fork and Biodiversity strategies targets in the framework of the 2030 Climate targets and the post 2020 Common Agricultural Policy, EUR 30317 EN, Publications Office of the European Union, Luxembourg, 2021, ISBN 978-92-76-20889-1, doi:10.2760/98160, JRC121368.

Beckman J., Ivanic M., Jelliffe J.L., Baquedano F.G., Scott S.G., (2020). Economic and Food Security Impacts of Agricultural Input Reduction Under the European Union Green Deal's Farm to Fork and Biodiversity Strategies, A report summary from the Economic Research Service of USDA, November 2020

Bremmer, J., Gonzalez-Martinez, A., Jongeneel, R., Huiting, H., Stokkers, R., & Ruijs, M. (2021). Impact assessment of EC 2030 Green Deal Targets for sustainable crop production.

Chiodi, A., Donnellan, T., Breen, J., Deane, P., Hanrahan, K., Gargiulo, M., & Ó Gallachóir, B. P. (2016). Integrating agriculture and energy to assess GHG emissions reduction: a methodological approach. *Climate Policy*, *16* (2): 215-236.

Cortignani, R., Gobattoni, F., Pelorosso, R., & Ripa, M. N. (2018). Green payment and perceived rural landscape quality: a cost-benefit analysis in central Italy. *Sustainabilit*y, 10(8), 2910.

Di Leo, S., Pietrapertosa, F., Loperte, S., Salvia, M., & Cosmi, C. (2015). Energy systems modelling to support key strategic decisions in energy and climate change at regional scale. Renewable and Sustainable Energy Reviews, 42: 394-414.

Ferrero A., Barozzi F., Mariani L., (2021). Strategie Farm to Fork e Biodiversità dell'UE - Impatto economico, ambientale e sulla sicurezza alimentare. Agrarian Sciences. https://www.agrariansciences.it/2021/09/strategie-farm-to-fork-e-biodiversita.html

Searchinger R.D., Wirsenius S., Beringer T., Dumas P., (2018). Assessing the efficiency of changes in land use for mitigating climate change. *Nature*, 564: 249-253.

Sehn, V., & Blesl, M. (2021). Implications of national climate targets on the energy-water nexus in Germany: a case study. *Journal of Sustainable Development of Energy, Water and Environment Systems*, 9(1), 5-0.

Schuh, B. et al. (2020). Research for AGRI Committee – The challenge of land abandonment after 2020 and options for mitigating measures, European Parliament, Policy Department for Structural and Cohesion Policies, Brussels.

Conclusions

This research illustrates the fundamental steps for the implementation of a modeling framework that integrates the Water-Energy-Food Nexus with a bottom-up technology-oriented approach typical of partial equilibrium energy models, to represent the agricultural system and investigate its development on medium -long period. The scenario analysis was aimed at assessing the impacts of EU agricultural policies and climate change in terms of resource and land use, food production and the environment.
The aim was also to explore the feasibility of a land use approach and to lay the foundations for the future integration of the agricultural module into a more complex energy system model in order to explore the potential synergies and drawbacks between the five main economic sectors (agriculture, industry, residential, tertiary, transport).

Agriculture, in fact, plays a crucial role in achieving the sustainable development goals as the rational use of resources (soil, water and energy) and adequate food production are essential to guarantee the well-being of the population, while adoption of sustainable agricultural practices contributes to mitigate the effects of climate change and support the resilience of the territory. In this context, a broad scientific debate is underway on the choice of modeling tools and indicators suitable to support the definition of policy strategies and to measure progress towards the achievement of sustainability objectives (SDGs).

The Nexus approach, increasingly used for an integrated vision of the main sustainability challenges, allows to highlight the interdependencies between the three key variables, Water-Energy-Food, and to better understand their role in energy, environmental and agricultural policies as well as to study the effects of climate change on them. On the other hand, a modeling framework based on the IEA-ETSAP methodology, expressly designed for long-term energy-environmental analyses, which identifies the least-cost paths to achieve the policy objectives, allows to guarantee transparency in the basic assumptions and a high level of detail in identifying possible strategies.

The integration of the Nexus in a partial equilibrium modeling approach based on the ETSAP-TIMES structure allows to develop an innovative modeling context useful for identifying the optimal allocation of energy and material resources in relation to different energy, environmental and physical constraints as well as assessing the effects of EU policies on agriculture, environment and energy and identifying the best strategies for their implementation. To develop the TIMES Land-WEF model, an innovative modeling approach was therefore adopted based on land use as a guiding variable. The model database includes non-energy resources among the raw materials in input and has crops, livestock and biomass as output. The model was customized and calibrated on the agricultural system of the Basilicata Region, a relevant case study for the Mediterranean region, providing for the subsequent integration with the TIMES Basilicata energy model from a circular economy perspective.

The representation of the agricultural system was therefore carried out taking into account the main agricultural and forest crops as well as the animal species characteristic of the Basilicata Region and most relevant to the local economy. Conventional and organic plant productions have therefore been modeled as processes, including water, fertilizers and active substances for crop protection among the incoming raw materials in addition to energy carriers.

The model, guided by land use, makes it possible to evaluate the effects of agricultural policy and climate change in terms of use of resources (energy, water, land use by crops) and agricultural productivity. In addition to this, the environmental impacts associated with agricultural activities can be considered, in particular the release of GHG emissions by livestock over a medium-term time horizon (2010 – 2060).

The scenario analysis highlights the most suitable crops to meet the various constraints in a minimum cost approach and provide a robust methodological framework for the identification of sustainable development strategy of agricultural sector that pointing out the best-suited cropping patterns. In particular, the Business as Usual scenario highlights that less energy-intensive crops (requiring fewer processing steps and less use of fertilizers and substances for crop protection) and non-irrigated crops will be privileged, also leading to a decrease of CO2 total emissions. The agricultural system would be then faced with a deficit in the production of cereals from conventional agriculture to be eventually compensated through an external supply using substitute products, and a partial reduction in the production of the fruit and vegetable sector, which now represents the spearhead of the Lucan agricultural system.

The results of the assessment of EU agricultural policy, in line with the main studies in literature, show that the implementation of the Farm to Fork strategy, contributing to the sustainability of the agricultural system and the achievement of climate neutrality by 2050 through the reduction of GHG emissions, could have the main effect collateral a significant reduction in agricultural production threatening the efficiency of the system in ensuring adequate resources.

Finally, the assessment of the response of the Basilicata region agricultural system to the increase in average temperature of 2 °C highlighted by the decrease in agricultural yields and land use points out the challenging problems that agriculture will have to face in the near future: lower water availability, soil degradation, food availability and safety.

It also highlights the necessity of improving the TIMES Land-WEF model to capture the many effects of climate change on the agricultural system and to identify suited indicators that can allow measuring these effects. Further modelling improvements will therefore focus on these aspects in order to analyse in detail and optimize the whole the food production chain.

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