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The multi-faceted effects of green innovation in the crop & livestock sector in Greece: Evidence with the FABLE Calculator

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Abstract

This paper explores the transformative potential of green innovation within Greece's agricultural sector. Leveraging the analytical power of the FABLE (Food, Agriculture, Biodiversity, Land Use, and Energy) Calculator, we quantify the impacts of enhanced crop and livestock productivity on key Agricultural, Forestry, and Other Land Use (AFOLU) environmental indicators. By employing empirical evidence and sophisticated modelling techniques, we investigate the intricate interplay between agricultural innovation and environmental sustainability. Examining the pathways under distinct scenarios of the FABLE Calculator, we demonstrate how improved crop and livestock practices can mitigate greenhouse gas emissions, reduce land degradation, and promote biodiversity conservation. We identify precision agriculture technologies like drones, soil moisture sensors, and variable rate technology advancements in precision livestock technologies such as automated feeding systems and health monitoring sensors as levers for bolstering agricultural productivity. We find that enhancing productivity in the livestock and crop sector significantly reduces GHG emissions from agriculture, with the result being most pronounced when embedded in a holistic transformational strategy following national commitments. Moreover, the paper elucidates the potential synergies and trade-offs associated with different agricultural strategies, offering insights into optimal pathways for sustainable development. In addition to its empirical findings, the paper delineates policy recommendations to support green innovation within the Greek agricultural sector, focusing on horizontal and vertical measures. Overall, this paper underscores the importance of integrating green innovation into agricultural policies to achieve both environmental and economic objectives. By harnessing the analytical capabilities of the FABLE Calculator, it offers valuable insights into the multifaceted effects of agricultural innovation, paving the way for evidence-based decision-making in sustainable agricultural development.

Keywords: Agricultural Productivity, FABLE, Green Innovation, AFOLU, GHG Emissions

Introduction

In recent years, the agricultural sector has faced increasing pressure to reconcile productivity gains with environmental sustainability, particularly in the context of climate change and biodiversity loss. Nowhere is this challenge more pressing than in Greece, a country with a rich agricultural heritage and diverse ecosystems. This paper delves into the multi-faceted effects of green innovation in Greece's crop and livestock sector, utilizing insights from the FABLE (Food, Agriculture, Biodiversity, Land Use, and Energy) Calculator to gauge the impact of enhanced productivity on key Agriculture, Forestry, and Other Land Use (AFOLU) variables. At the heart of this discourse lies an examination of the interplay between increased crop and livestock productivity and its repercussions on critical AFOLU indicators, notably greenhouse gas (GHG) emissions, biodiversity conservation, and land use efficiency.

Agricultural productivity holds immense importance in Greece, deeply rooted in its history, topography, and cultural heritage, contributing significantly to economic output and employment. Productivity is a critical factor in preservation and enhancement, as traditional crops and farming methods are integral to its identity. A prime example is olive cultivation, a centuries-old tradition that positions Greece as a leading global producer of olives and olive oil. Having said that, a more productive agricultural sector boosts economic growth, as agriculture is a significant contributor to Greece's GDP. Increased productivity allows Greece to utilize its diverse landscapes and favorable climate for more food and agricultural products, boosting revenue, creating jobs, and strengthening the economy. Finally, enhancing agricultural productivity aligns with sustainability goals by efficiently using resources like water and land, helps mitigating environmental impact while sustaining output. These sustainable practices preserve Greece's natural beauty and resources for future generations and cater to the rising demand for eco-friendly products globally.

This paper critically assesses the status of key technologies poised to drive productivity gains in the Greek agricultural landscape. Specifically, we scrutinize the potential of precision agriculture technologies in enhancing efficiency while minimizing environmental externalities. Leveraging the analytical tools of the FABLE Calculator, which offers a robust framework for modeling and analyzing such complex interactions, we aim to provide empirical evidence shedding light on the outcomes of intensified agricultural practices in Greece. We do so by examining the effects of productivity increases in a Business-as-Usual Scenario as well as embedded in a series of reforms and policies adhering to Greece's national and international commitments. Our results show a clear emission abating effect of productivity surges in the crop and livestock sector, leading to a drop of 29.2% in total GHG emissions by 2050. The effect is accenuated when we consider full abiding by National commitments, whereby the decline in emissions reaches 62% by mid-century compared to 2020 levels. The results are mainly driven by a pronounced decrease in livestock emissions and are coupled with significant cost decreases for the Greek agricultural sector.

Additionally, our inquiry extends to an examination of the policies necessary to support the adoption and diffusion of these technologies in a manner that is not only efficient but also equitable. Recognizing the socio-economic dimensions inherent in agricultural transformation, we advocate for policies that prioritize both environmental sustainability and social justice, thereby ensuring that the benefits of green innovation are shared inclusively across all segments of society.

The structure of this paper is the following: section 2 presents the FABLE approach in evaluation sustainability on agri-food systems; section 3 introduces important technologies in the field of enhancing crop and livestock productivity, along with its multiple benefits and its relevance to Greece based on its profile,; section 4 outlines the basic projections using the FABLE Calculator; section 5 provides policy recommendations, and the final section concludes.

Land-use and Climate Scenarios using FABLE

The FABLE Approach

The FABLE Consortium is a global collaborative of researchers who develop national pathways that are consistent with global sustainability objectives, such as Sustainable Development Goals (SDGs) and the Paris Climate Agreement targets. Calculations and development of sustainable pathways are carried out using the FABLE Calculator, a potent tool including 88 raw and processed indicators on the agricultural sector, the economy and population (Mosnier, 2020). Using a demand-based approach the Calculator projects levels of greenhouse gas (GHG) emissions, land use and land use change, biodiversity, and economic indicators. The pathways are developed following the combination of predetermined and custom-built scenarios across 22 thematic categories covering climate change scenarios, policy implementation, behavioural aspects, dietary patterns, and trade. The process yields a portfolio of more than 1.5 billion potential pathways for 2050 which allow for critical evaluations of their feasibility, distributional aspects, and economic efficiency.

Business as usual and Enhanced Productivity Pathways

The first set of results describes the change in key AFOLU variables and indicators from an exogenous increase in Crop and Livestock productivity whilst maintaining a Business as Usual (BAU) scenario for all other aspects, following the "Current Trends" pathway for Greece (see Appendix II). Using the 22 available levers in the FABLE Calculator, the baseline pathway assumes no significant policy and behavioural changes in Greece for the 2020-2030 horizon. Following trends of the 2000-2015 period, this pathway encompasses a minor uptick in economic activity, no expansion in national protected areas and no change in national dietary patterns. Stagnant agricultural productivity is defined as the 2000-2010 average productivity growth for the livestock sector and unchanged productivity at the 2020 level for crop agriculture. Furthermore, the trajectory is calculated assuming no substantial shift in biofuel demand, no afforestation target, and no change in post-harvest losses. The baseline pathway representing current trends in the Greek AFOLU sector is embedded in a global GHG concentration trajectory that would lead to a radiative forcing level of 6 W/m2 (RCP 6.0), or a global mean warming increase likely 2-3°C above pre-industrial levels.

To illustrate the dynamics uncovered by an increase in agricultural productivity we proceed in a two-fold fashion. First, we introduce the boost in agricultural productivity within the BAU scenario, leaving all other policy parameters unchanged. In the case of the livestock sector this refers to an absolute reversal of the negative average productivity growth of the 2000-2010 for pigs, cattle, cattle milk, and eggs[1]. High productivity growth in the crop sector is associated with a closure of the yield gap by at least 80%, compared with stability in the baseline scenario.

Having established the projected changes brought upon the Greek agricultural and food system following an increase in crop and livestock productivity in a stand-alone fashion, we turn to include the productivity shifts in the "National Commitments" pathway Greece (see Appendix II). The quantitative and qualitative targets which are considered for this pathway are extracted from a thorough review of key policy and legislative documents at the national and the EU level, such as Greece's NECP, the Development Plan for the Greek Economy (Pissarides et al., 2020) and all relevant documents from the EU Green Deal. Apart from increased productivity in the crop and livestock sector, the pathway is underpinned by medium to high speed of economic growth, shift to a healthy diet[2], a pronounced improvement in the country's agricultural trade balance reflecting the strategy for outward-oriented economic growth and productivity is expected to surge both for crops and for livestock production. This Pathway is embedded in a global GHG concentration trajectory that would lead to a lower radiative forcing level (RCP 4.5) and assumes expansion of protected areas and an increase in the deployment of organic practices in agricultural land[3].

[1] All negative productivity growth rates are multiplied by -1 in this scenario. The exception is milk from sheep and goats, whereby the 2000-2010 average of 1.42% is multiplied by 0.7 as per the FABLE Calculator operation.

[2] As prescribed by the Lancet Committee - EAT-Lancet

[3] The detailed assumption of bothe FABLE pathways are illustrated in Appendix I.

Cutting-Edge Technologies for Crop and Livestock Productivity

The advent of Precision Agriculture

In modern agricultural management, boosting productivity is crucial, especially through technologically driven methods. Precision agriculture (PA) stands out as an essential approach, employing cutting-edge technologies like geospatial data and real-time monitoring systems to enhance the precision of resource application and yield optimization. This method is particularly valuable as it promotes sustainable farming practices by enabling the precise application of critical resources such as water, fertilizers, and pesticides, thus minimizing environmental impact and enhancing economic outcomes. Therefore, the integration of precision agriculture is imperative for achieving superior productivity in both crop and livestock sectors.

As defined by the International Society of Precision Agriculture (ISPA), "Precision Agriculture is a management strategy that gathers, processes, and analyzes temporal, spatial, and individual plant and animal data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability, and sustainability of agricultural production." (ISPA, 2024). PA utilizes specialized technologies in two main sectors: crop and livestock. In crop production, PA employs positioning systems, drones, and sensors to precisely monitor crop health and optimize water use. Additionally, Variable Rate Technology (VRT) allows for tailored application of fertilizers, pesticides, and seeds, enhancing yields while reducing waste. In livestock management, technologies like identification tags and tracking systems provide real-time data on animal location and behavior. Automated feeding systems adjust to the nutritional needs of each animal, and health monitoring sensors track vital indicators such as heart rate and body temperature, enabling early illness detection and improving overall productivity in livestock farming (FAO, 2017).

Precision Agriculture Technologies for crop productivity

Various technologies directly or indirectly contribute to precision agriculture. Some are dedicated to data collection, such as sensors and drones, while others focus on management and input application, like Variable Rate Technology (VRT) and automated systems. The technologies that are directly involved in PA are described below and summarized in Table A3 in Appendix II.

Geographic Information Systems and Global Positioning System

Geographic Information Systems (GIS) enable precise management of farming activities by mapping field boundaries, irrigation systems, and problem areas. The technology integrates various data sources to provide a comprehensive view of farm operations. GIS allows for spatial analysis and visualization, helping farmers understand variability in soil and crop conditions. It supports decision-making by optimizing the application of fertilizers, pesticides, and water (Raihan, 2024). Global Positioning System technology provides precise field navigation, reducing overlaps and missed areas during operations such as planting and harvesting (Yousefi & Razdari, 2014). GPS auto-guidance typically involves a Global Navigation Satellite System (GNSS) receiver, controller, user interface, attitude sensors, and a steering actuator, offering centimeter-level accuracy with RTK correction. This technology significantly improves precision in tasks such as planting, spraying, and harvesting, enhancing overall productivity and resource efficiency in agriculture (Adamchuk et al., 2008).

Drones and Remote Sensing

Drones and Remote Sensing technologies offer a detailed, real-time monitoring of crops and environmental conditions. Drones equipped with multispectral cameras can monitor crop health across large areas quickly, guiding targeted interventions that are crucial during critical growth stages. Regular drone flights can monitor crop health over time, allowing farmers to identify stressed areas caused by pests, diseases, or insufficient nutrients. This timely detection enables targeted interventions, minimizing crop damage and reducing resource waste. Drones can be equipped to distribute fertilizers, pesticides, or seeds. They can apply these inputs variably across a field, targeting areas that need more or less, based on real-time data and pre-programmed maps, thus optimizing resource usage, and boosting yields (Mazeed & Maurya, 2022). By using thermal or hyperspectral cameras, drones can assess soil moisture and identify areas that are too dry or adequately hydrated.

This information helps in managing irrigation systems more efficiently, ensuring that water is used precisely where it's needed (Mogili & Deepak, 2018; Rane & Choudhary, 2023). Remote sensing, integrated with GIS and data analytics, enables precise agricultural interventions that optimize resources and efficiency (Raihan, 2024). It allows farmers to customize irrigation, fertilization, and pest control, boosting yield and minimizing environmental harm. Additionally, it aids in early detection of diseases, pest issues, and nutrient shortages, facilitating timely and informed actions that enhance crop health and decrease chemical dependency. Remote sensing also helps monitor land use, soil erosion, and promotes sustainable practices, thereby revolutionizing agriculture with data-driven decision-making for improved productivity (Verma et al., 2023).

Soil and Plant Sensors

Soil and Plant Sensors are pivotal in precision agriculture, providing detailed, real-time insights into soil conditions and plant health. Soil sensors measure variables such as moisture, temperature, and nutrient levels, allowing for precise irrigation and fertilization based on current soil conditions (Adamchuk et al., 2020). These sensors help reduce water usage and improve crop yields by ensuring that plants receive the optimal amount of nutrients and water. Plant sensors, including those that assess chlorophyll content and canopy temperature, monitor plant health and stress levels, enabling timely interventions to promote healthy crop growth and maximize yields (Gebbers & Adamchuk, 2010). By integrating data from both soil and plant sensors, farmers can implement site-specific management strategies that enhance productivity and sustainability (Serrano et al., 2021).

The direct technologies become even more effective when combined with indirect technologies. These include Variable Rate Technology (VRT), which allows for precise application of inputs like seeds and fertilizers based on specific field conditions, reducing waste, and increasing yields (Javadi, 2022; Pawase et al.,2023). Precision Irrigation optimizes water use by applying it only where and when needed, leveraging advanced sensors and data analytics (Bhushan et al., 2023). Automated Steering Systems (ASS) guide machinery with high accuracy, reducing overlaps and gaps, thus conserving fuel and resources while improving crop yields (Mousazadeh, 2013). Yield Monitoring collects real-time data during harvest to create detailed maps of crop yield variability, providing better insights for farm management (Fulton et al., 2018). Technological solutions associated with Internet of Things (IoT) connect various sensors and devices to gather and analyze data on soil moisture, temperature, and crop health, facilitating informed decision-making and resource optimization (Shahab et al., 2024).

Precision Agriculture Technologies for livestock productivity

In parallel with PA technologies that target crop productivity, a range of innovative technologies has been developed to enhance efficiency and productivity in livestock management. These advancements aim to improve various aspects of livestock farming, including health monitoring, feeding efficiency and overall farm management. The technologies and their applications in modern livestock farming are outlined below and summarized in Table A4 in Appendix II.

Electronic Identification and GPS Tracking Systems

Radio-Frequency Identification (RFID) tags and GPS collars are key technologies in precision livestock management, providing critical data on animal location, movement, and behaviour. RFID tags, attached to individual animals, enable quick identification and data collection, such as health records and breeding information. Tracking collars offer real-time location tracking, helping manage grazing patterns and detect changes in animal movements that might indicate distress or illness. Together, these technologies enhance herd management by automating monitoring and improving the accuracy of data. This leads to better decision-making regarding feeding, health interventions, and overall herd management (Singh et al., 2014; Doğan et al., 2016).

Automated Feeding and Milking Systems

Automated Feeding and Milking Systems revolutionize livestock management by enhancing efficiency and ensuring optimal animal health. Automated Feeding Systems (AFS) deliver precise quantities of nutrition tailored to the specific needs of each animal, improving feed efficiency and growth rates (Pezzuolo et al., 2016). Similarly, Automated Milking Systems (AMS, also known as robotic milking systems, allow for consistent and gentle milking, increasing milk yield while reducing the stress on dairy animals (John et al., 2016; Cogato et al., 2021). These systems collect data on feeding habits and milk production, enabling farmers to make informed decisions about diet adjustments and health interventions. This integration of technology not only maximizes productivity but also supports the welfare of the animals, leading to more sustainable farming practices (Simitzis et al., 2022).

Health Monitoring Sensors

Health Monitoring Sensors are essential tools in precision agriculture for maintaining animal welfare and enhancing productivity. These sensors are attached to livestock to continuously track vital signs like heart rate, temperature, and activity levels, allowing for early detection of health issues (Berckmans, 2017). By providing real-time data, these devices enable timely interventions, preventing disease spread and reducing mortality rates. The insights gained from health monitoring also assist in optimizing breeding programs and managing stress among the herd. This technology supports more precise and proactive management of animal health, leading to improved efficiency and lower veterinary costs (Berckmans, 2017; Papakonstantinou et al., 2024).

Precision Agriculture Technologies: Insights from Greece

Agriculture is a fundamental sector in Greece, playing a crucial role in the country's economy, contributing approximately 4% to GDP (World Bank, 2022). This contribution is significant in maintaining economic stability and fostering growth, particularly in rural areas where agricultural activities provide vital employment opportunities. The sector employs about 11% of the Greek workforce (World Bank, 2022), highlighting its importance in sustaining livelihoods in rural communities and preventing urban migration. Greece is renowned for several high-value agricultural products that have significant market shares in domestic and international markets. The country is one of the top producers of olive oil, contributing significantly to global supply. Additionally, Greece produces a variety of fruits and vegetables, such as tomatoes, peaches, and grapes, which are essential for both local consumption and export markets (Figure A1). These exports play a vital role in the country's economy, supporting trade balance and generating income.

From the above, it becomes even more evident that safeguarding the agricultural sector is imperative. Agricultural production in Greece is inextricably linked with the use of fertilizers and pesticides. The correlation coefficient between fertilizer use and agricultural production is approximately 0.71, indicating a strong positive correlation. This suggests that an increase in fertilizer use is associated with a corresponding increase in production. Similarly, the correlation coefficient for pesticide use stands at approximately 0.40, signifying a moderate positive correlation, which indicates that higher pesticide usage is also associated with increased production levels. Hence, adopting advanced technologies to reduce the use of production inputs is crucial for improving the economic sustainability of the agricultural sector in Greece.

PA holds immense potential to address significant challenges in Greece's agricultural sector, such as fragmented land holdings, water scarcity, and the need for modernization. Various studies support the significance of PA in Greece. For instance, a study by Kleftodimos et al. (2022) found that the adoption of PA practices in Greek dairy farms significantly improved sustainability and reduced greenhouse gas emissions. The study highlighted those economic incentives, particularly premiums, were more effective than penalties in encouraging adoption. In Thessaly, two farms that implemented PA practices showed increased gross margins and reduced production costs. Another study by Kalfas et al. (2024), analyzing data from 240 farmers, found that technologies like AI and IoT, in addition to precision agriculture, enhance resource efficiency, reduce environmental impacts, and increase yields. The most used technologies were precision agriculture (35.4%), AI technologies (27.9%), and aerial drones (17.9%). Key factors influencing adoption included education (44.6%), access to capital (24.1%), and internet connectivity (17.9%).

Despite the proven benefits, the adoption of precision agriculture in Greece remains low. Various studies reveal several factors contributing to this slow uptake. Awareness and education are significant factors. A study in Central Greece involving 375 crop producers found that only 16.3% were familiar with PA, although 60.8% believed it essential for the future. Factors such as gender, education, and technology familiarity were significant in influencing adoption (Koutridi et al., 2018). Financial constraints are another major barrier. For example, in Central Macedonia, a study with 220 young farmers revealed that while 56.9% were aware of PA practices, 82.3% cited high investment and maintenance costs as significant barriers to adoption (Tsiouni et al., 2024).

The lack of technical support and necessary infrastructure further hampers the adoption of PA. High initial costs and limited technical support were significant barriers, as found in a study by Barnes et al. (2019). Specific regional challenges such as variable soil qualities and water scarcity necessitate intelligent farming approaches. However, the fragmented land holdings and the small size of farms complicate the widespread adoption of PA technologies (Gemtos et al., 2004; Barnes et al., 2019).

The study of PA applications in cotton fields of Greece over a three-year period highlighted significant variability in soil and yields within small fields. Precision agriculture techniques helped manage this variability, improving crop management and justifying the investment in PA technology (Gemtos et al., 2004). Another study focusing on precision irrigation technologies in olive and cotton farming in Messenia and Thessaly revealed that despite potential benefits like optimized water use and increased crop yields, adoption remained low due to factors such as environmental consciousness and perceived economic benefits (Kakkavou et al., 2024).

In conclusion, PA has the potential to revolutionize farming in Greece by enhancing productivity, sustainability, and resource efficiency. However, its adoption is hindered by factors such as lack of awareness, financial constraints, and insufficient technical support. To bridge this gap, strategic investments, supportive legislation, and targeted educational programs are essential. Promoting PA through economic incentives, robust advisory services, and ongoing support can significantly improve adoption rates and lead to more sustainable farming practices in Greece.

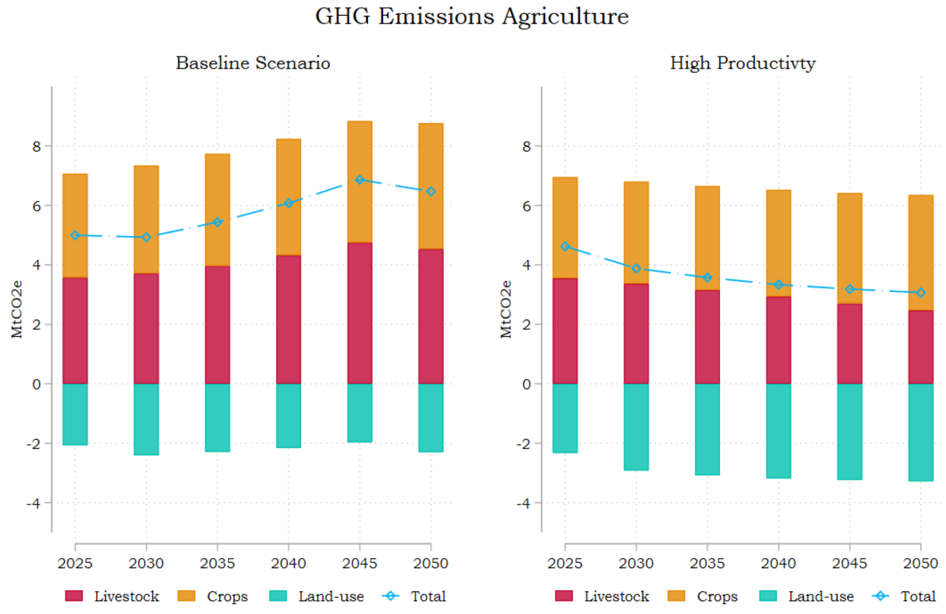
Results from the FABLE Calculator

This section presents the indicative results from the scenarios described in Section 2 using the FABLE Calculator. Enhancements in crop and livestock productivity are included first in the BAU pathway and, as a second step, are commingled with a set of reforms stemming from Greece's *national commitments* (see Appendix II).

Maintaining all policy and technology aspects in the baseline scenario except for an upward productivity shift in the crop and livestock sector significantly alters the agricultural GHG emissions pathway towards mid-century as shown in figure 1. Total emissions are halved compared to the baseline scenario reaching 3 Mt in CO2 equivalents by 2050, thus recording a 29% reduction in comparison to 2020 levels. Furthermore, this underscores a cumulative 73.4% drop from the GHG emission levels for Greek agriculture in 2000, indicating sharp compliance to EU green transformation objectives.

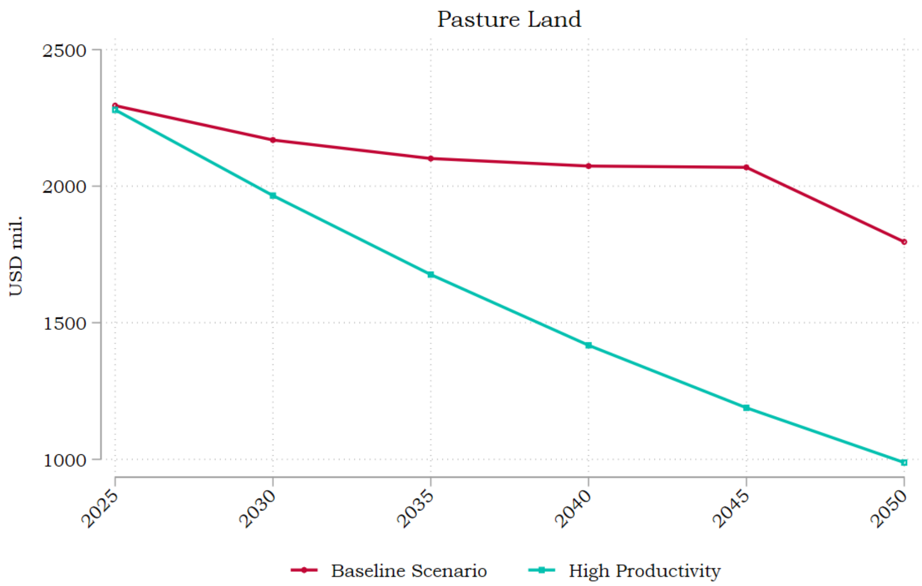
The result is mainly driven from the drastic reduction in livestock emissions (2.47 Mt in 250 compared to 4.53 Mt under the baseline scenario) as well as the elevated emission withdrawals induced by land use change (3.28 Mt in 250 compared to 2.31 Mt under the baseline scenario). The latter reflects the reduced needs for land expansion as the enhanced productivity increases yield without requiring vast amounts of input, corroborated by the decline in pastureland (Figure 2). Agricultural emissions tied to crop production also diminish under the high productivity scenario, diverging significantly from the baseline after 2035 according to the projections.

Figure 1: AFOLU Emissions - Baseline and Increased Productivity Scenarios



Source: FAO and Authors' Calculations

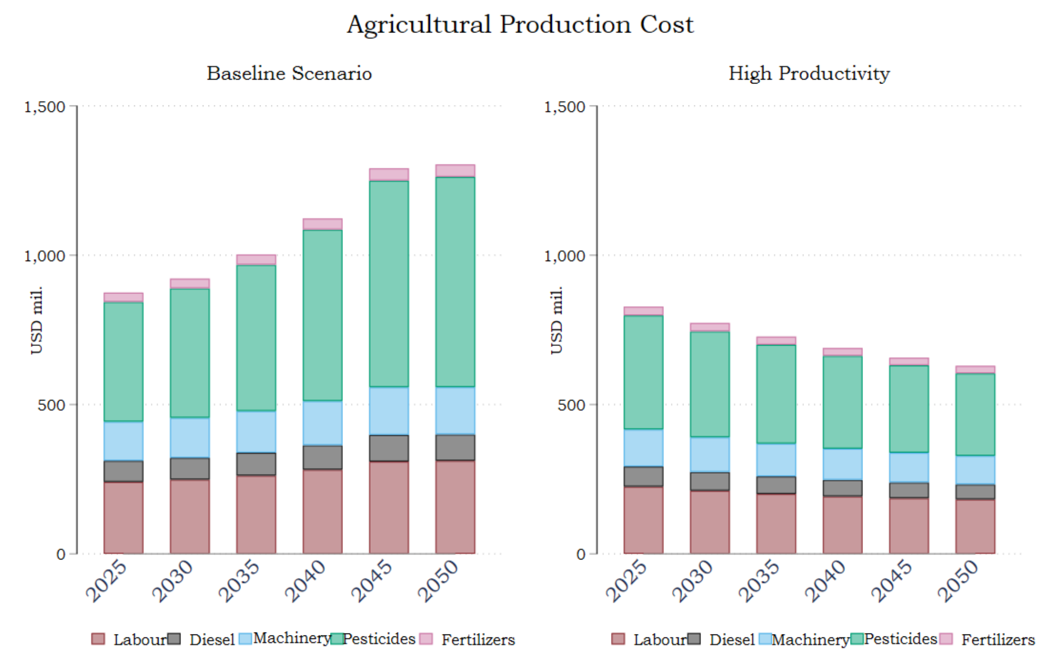
Figure 2: Pastureland - Baseline and Increased Productivity Scenarios



Source: FAO and Authors' Calculations

An important aspect of a surge in agricultural productivity is the double dividend of climate change mitigation and increased competitiveness of the domestic agricultural sector. Figure 3 clearly illustrates the diverging trajectories in production costs for Greek agricultural producers, a heavily debated issue following the 2023 extreme weather events and the 2023-27 CAP[4]. Total costs gradually decrease under the assumption of high productivity from 828 million euros in 2025 to less than 630 million in 2050, driven predominantly by diminishing pesticides costs, which represent the lion's share in total expenditures. Specifically, the producers' expenses on fertilisers mark a 27.5% reduction in the 2025-2050 period in the high productivity scenario thus representing just the two fifths of the respective cost under the business-as-usual scenario. Fertiliser costs drop somewhat less impressively by 14.8% over the 25-year period, however the divergent upward trajectory in the baseline scenario results in a cost saving gain of almost 40% for domestic producers as a result of enhanced productivity in the sector.

Figure 3: Production Costs - Baseline and Increased Productivity Scenarios



Source: FAO and Authors' Calculations

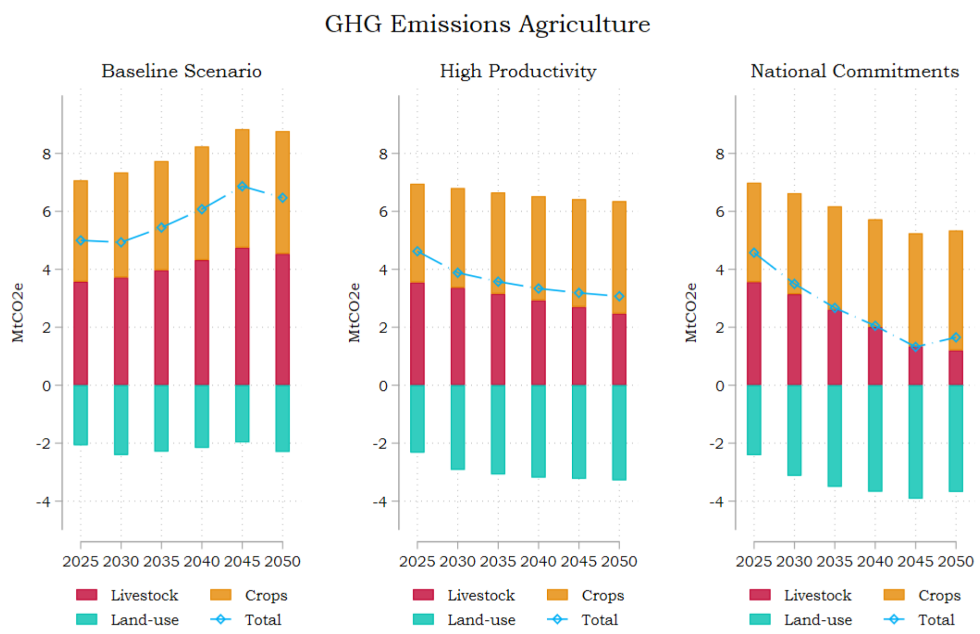
As a further exercise, we incorporate the productivity surge in the wider range of reforms pertaining to the implementation of all national commitments outlined in Section 2 (see Table A2 in the Appendix for a full description of the targets). As shown in Figure 4, a shift to higher agricultural productivity coupled with behavioural change, pronounced

[4] The European Parliament's study on the impact of extreme climate events on agricultural production in the EU explores how the increasing frequency of extreme weather events, exacerbated by climate change, poses significant challenges for agricultural productivity and costs. See the European Parliament's study here.

economic growth and more stringent monitoring of environmental policies results in a substantial abatement of GHG emissions from agriculture in Greece, reaching 1.6 Mt CO2e in 2050. The latter represents a 62% drop from 2020 levels in 30 years and a 46% reduction compared with the High Productivity scenario which clearly indicates the need for a holistic approach to the sustainable transformation of the agricultural sector.

Livestock emissions drive the emissions abatement by large in this scenario, more than the High Productivity case since meat consumption is expected to deteriorate as the population shifts to healthy dietary patterns[5]. Emissions related to crop agriculture are marginally elevated compared to the High Productivity Scenario, reflecting the change in demand towards plant-based dietary patterns, however, remain moderately subdued compared to the baseline scenario. Finally, emissions savings from land use and land use change are modestly increased under the National Commitments scenario, reflecting the clearly defined afforestation targets and the halt of urban area expansion assumed.

Figure 4: AFOLU Emissions - Baseline, Increased Productivity and National Commitment Scenarios



Source: FAO and Authors' Calculations

Fostering productivity growth is a key policy target for the Greek agricultural sector. Having said that, employment in the sector remains above 10% and places Greece among the top three spots in the EU's relevant statistics. Hence, supporting agricultural jobs is pivotal to the overall national economic development strategy (Pissarides et al., 2020; Loizou et al, 20919). As shown in Figure 5, promoting agricultural productivity

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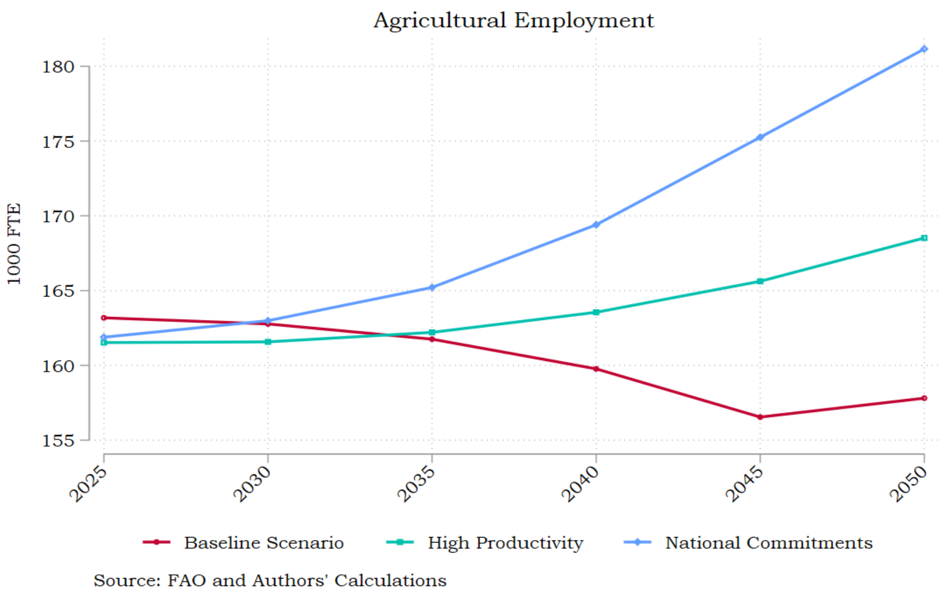
[5] As outlined by the LANCET Committee, see https://www.thelancet.com/commissions/EAT

growth yields benefits for agricultural employment, however much more so when it is embedded in an integrated reform framework towards sustainable agriculture.

Employment gains in the National Commitments scenario materialise from 2035 onwards and result in a steady increase in active jobs throughout the 30-year period. By 2050 the tangible effect is 24 thousand more employment positions (FTE) compared to the baseline scenario and 13 thousand against the stand-alone productivity enhancement pathway for Greece. The result is driven by the uptick in economic activity assumed in the National Commitments and even though no growth in irrigated harvested area is assumed, highlighting the decoupling potential of inclusive economic growth and GHG emission reduction.

Figure 5: Agricultural Employment - Baseline, Increased Productivity and National Commitment Scenarios



Policy recommendations for enhancing Agricultural Productivity

Horizontal Policies

In essence, promoting innovation and technological change in the Greek agricultural sector is an integral part of the overall technological transformation of the Greek economy. Greece is a Moderate Innovator in the EU context according to the EU Innovation Scoreboard (European Commission, 2023), exhibiting a strong dynamic in tertiary education and innovative SMEs. Nonetheless, it is traditionally lagging in building a domestic innovation system (and actively participating in regional innovation systems), which would ensure the dissemination of knowledge and foster inter-sector collaborations[6]. The Greek economy is struggling to commercialise R&D efforts into patents, trademarks, and design applications and, more importantly for the case of agriculture, does not develop strong inter-sectoral ties which would ensure a pipeline from research to production (Kaloghirou et al., 2021). Promoting linkages between knowledge creation and application has been a long-time challenge for technological transformation in the Greek economy and tackling it could yield significant dividends in enhancing well-being and meeting sustainability targets (Chrysomallidis, 2012; Anyfantaki et al., 2023).

Enhancing lifelong learning and expanding it to actively cater to the agricultural population's needs is pivotal in fostering technological transformation in the agricultural sector. The learning process needs to actively connect the research and innovation sector to the application of innovative practices, highlighting the mitigating effects on GHG emissions as well as the employment- and growth enhancing effects of key technologies that boost agricultural productivity. Furthermore, as skills play a pivotal role in harnessing the productivity gains associated with precision agriculture and advanced technology in general, adding in-the-field activities in the academic curricula of Greek universities tangent to agriculture will bolster the interlinkages between knowledge and practice. Bold reforms in the way the country perceives learning, therefore, hold great potential for enhancing crop and livestock productivity. Finally, as highlighted by Pissarides et al. (2020), increasing the average size of Greek agricultural holdings through incentives for cooperation and clearly defined property rights is a crucial step towards leveraging economies of scale and enhancing productivity.

An indirect channel, which nonetheless does not entail fiscal burden for the Greek economy, is the promotion of Foreign Direct Investment (FDI) in the agricultural sector, contingent on a discrete level of screening to ensure that multinational enterprises are

[6] The lack of integration of the business and -even more- the agricultural sector in the knowledge creation and dissemination process has been a standing characteristic of the Greek post-war economy, highlighted in Vaitsos and Giannitsis (1987).

close to the sectoral technological frontier and are investing in knowledge exchange rather than resource extraction. Productivity gains can be realised within the sector either through imitation effects or enhanced competition, a process known as *horizontal spillovers* (Javorcik et al, 2018; Irsova & Havranek, 2013). Having said that, FDI in downstream sectors such as food manufacturing can also enhance agricultural productivity through *backward linkages* stemming from advanced practices of multinational corporations leading to higher standards for suppliers, increased competition and training and technology transfer activities (Javorcik, 2004; Amendolagine et al, 2019).

Following the pronounced upswing in inward FDI flows after 2016, there is a latent potential for agricultural productivity gains in Greece, especially considering the host countries' prominent position in the technology spectrum (Dellis, 2018)[7]. Nonetheless, the realization of productivity spillovers is contingent on domestic absorptive capacity, hence the policies aimed at improving infrastructure and fostering skills are material in this aspect as well (Crespo et al., 2009; Javorcik et al, 2018). According to the latest data from the Bank of Greece, Agriculture, Forestry and Fishing represent less than 0.5% of inward FDI flows after 2010. However, the sector of Manufacturing of Food and Beverages documented inbound annual flows of more than 300 million after 2018, thus increasing its share over total FDI flows to approximately 6% and its share over total manufacturing FDI to 40-50% in the 2018-2022 period. The data underscore the need both to attract MNC participation in the agricultural sector and also enhance domestic absorptive capacity to generate positive spillovers from the investment prone upward sector.

Vertical Policies

To further encourage the adoption of precision agriculture technologies in Greece, a series of vertical policies and initiatives can be implemented. These efforts aim to provide comprehensive support to farmers, develop sustainable technological infrastructures, and address the unique geographical challenges of the country.

A crucial framework in this endeavor is the Agricultural Knowledge and Innovation Systems (AKIS), designed to connect farmers, research institutions, and the private sector. By facilitating knowledge transfer and collaborative innovation, AKIS helps overcome barriers such as high initial costs and technical complexity by providing tailored training and support. Enhanced by the CAP 2023-2027, AKIS will fund initiatives promoting sustainable and competitive agricultural practices, ensuring a holistic approach to modernizing Greek agriculture (Amerani & Michailidis, 2024).

Additionally, creating a national registry of technical support specifically for precision agriculture technologies and guidance services can significantly enhance the adoption of new technologies and practices among farmers. This registry would comprise experts in precision agriculture who can provide personalized advice, training, and recommendations tailored to each case and field based on size and product type. An

[7] https://www.bankofgreece.gr/en/statistics/external-sector/direct-investment/direct-investment---flows

exemplary model is the Farm Advisory System (FAS) by the Greek Ministry of Rural Development and Food, which offers advisory services to farmers to improve agricultural practices and technology use.

The creation of a national registry of local sensor systems combined with digital infrastructure for processing open data across the entire country can be highly effective in addressing the spatial and temporal variability of Greece's geomorphology. This initiative would involve setting up local sensor networks and a digital framework to process and analyze open data, enabling better management and utilization of Greece's diverse agricultural landscapes. The "GAIA Sense" project in Greece, for instance, uses a network of sensors to collect real-time data on soil conditions, weather, and crop health. This data is then analyzed to provide actionable insights to farmers, helping them make precise decisions regarding irrigation, fertilization, and pest management. Such technologies optimize resource use and enhance productivity. Establishing smaller, localized projects can further ensure that all farmers, regardless of scale, have access to these advanced tools.

Moreover, setting up regional digital hubs focusing on precision agriculture can act as centers of excellence, providing farmers with access to the latest technologies and training. These hubs can host workshops, demonstrations, and pilot projects to showcase the benefits of precision agriculture. Initiatives such as the "Smart Farming Initiative" exemplify this approach, offering farmers access to advanced technologies and support services, thus driving the widespread adoption of precision farming practices within the region.

To support these technological advancements, innovative financial models such as micro-financing options and low-interest loans specifically tailored for precision agriculture investments can be introduced. These financial instruments can help smaller farmers afford the initial costs of adopting new technologies, making advanced tools more accessible to a broader range of farmers (fi-compass, 2023).

Conclusion

Sustainable food and agricultural systems are paramount for Greece's climate-resilient development due to the nation's geographical and climatic vulnerabilities. Greece faces increasing challenges such as water scarcity, soil degradation, and extreme weather events induced by climate change. Addressing these challenges necessitates a paradigm shift towards sustainable agricultural practices and food systems. This transition is contingent upon the adoption of technological advances and innovative solutions that enhance crop and livestock productivity.

We outline key technologies which have an enormous potential for increasing agricultural productivity and review their status in Greek agriculture. Moreover, we showcase the potential of increasing livestock and crop productivity to reduce greenhouse gas (GHG) emissions related to agriculture in Greece and offer actionable insights for policymakers and stakeholders. Utilizing projections from the FABLE calculator, the study presents a compelling case for strategic interventions in agricultural practices to align with sustainability goals. An increase in livestock and crop productivity drastically reduces GHG emissions from agriculture, driven primarily from diminishing livestock emissions and elevated negative emissions from land use.

In addition, the cost burden from producers is ameliorated to a great extent, owing greatly to the sharp drop of pesticides used in agricultural production. The results are pronounced when increases in productivity are embedded in a wider reform scenario reflecting the country's national commitments and adherence to EU green targets. Support for agricultural productivity growth commingled with a surge in economic activity, shifts to healthier dietary patterns and more stringent environmental policies halting biodiversity loss and protecting ecosystem services significantly promote admissions abatement, job creation and competitiveness in the Greek agricultural sector in the 30-year horizon.

The findings of the paper underscore the immense potential of increasing livestock and crop productivity to mitigate GHG emissions in Greece. The role of policies is material, including horizontal measures that enhance digital skills within the agricultural sector, a reform of formal and lifelong learning to enhance dissemination of knowledge into practice and promoting strategic FDI inflows in the agricultural and downstream sectors. Furthermore, vertical policies, including the establishment of a national registry for precision agriculture, the development of local sensor networks, and the creation of regional digital hubs, are vital for facilitating technology adoption, enhancing accessibility, and driving sustainable growth.

By implementing targeted policies that promote sustainable agricultural practices, leverage innovation, and enhance collaboration, Greece can move towards a more resilient and environmentally responsible agricultural sector while contributing to global climate objectives. Ultimately, the sustained increase in crop and livestock productivity forms the backbone of a sustainable agri-food system in Greece. It ensures food security, enhances economic viability for farmers, and protects the environment, creating a balanced approach that supports long-term sustainability.

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Appendix I: Greece Current Trends and National Commitments

Tables A1 and A2 present the description of the distinct pathways for the Greek agri-food sector, as documented in the [FABLE 2023 Scenathon](#)

Table A1: Pathway Narratives

CURRENT TRENDS	NATIONAL COMMITMENTS
We do not act differently than the past decade / today	National actions/policies are aligned with national commitments
The Current Trends Pathway projects key elements of the food, land-use, energy, and biodiversity systems conditional on no significant policy and behavioral changes in Greece for the 2020-2030 period. The continuation of business as usual implies high urbanization and an uptick in economic activity, no change in dietary consumption for the general population, 50% surge in key exports and increased reliance on food imports. Moreover, we assume no substantial shift in biofuel demand, no afforestation target and no change in post-harvest losses. This Pathway is embedded in a global GHG concentration trajectory that would lead to a radiative forcing level of 6 W/m2 (RCP 6.0), or a global mean warming increase likely 2-3°C above pre-industrial levels.	Under the National Commitments Pathway, we underscore specific numerical and qualitative targets based on Greece's NECP, the Pissardies Committe Plan for the Greek Economy and the commitments accruing from EU participation. The pathway entails medium to high speed of economic growth, shift to a healthy diet (as described by the Lancet Committee), and reduced imports. Nonetheless,exports are expected to double by 2050 reflecting the country's aspiration for outward-oriented economic growth and productivity is expected to surge both for crops and for livestock production. This Pathway is embedded in a global GHG concentration trajectory that would lead to a lower radiative forcing level (RCP 4.5) and assumes expansion of protected areas and an increase in agricultural land under organic practices.

Table A2: Pathway Assumptions

Topic	Indicator	CURRENT TRENDS	NATIONAL COMMITMENTS
1. Macroeconomics	**1.2)** GDP per capita	2% y-o-y Growth	3.5% y-o-y Growth until 2030
	1.3) Population	1.5 - 2.5 million reduction by 2050	Maintain population no less than 10 million
	1.4) Inflation	4.2% in 2023 2.4% in 2024	2% y-o-y
	1.5) Inequalities	Gini Index 33.5 in 2020 - moving away from Target according to SDG 10	Gini Index drop below 30 by 2030
2. Land	**2.1)** Constraints on agricultural expansion / deforestation	Promotion of no deforestation and expansion of agricultural land tied to agroforestry targets	Increase Legislation Stringency regarding deforestation for agricultural expansion and enhance monitoring and implementation
	2.2) Afforestation, and forest plantations targets	3.5 - 4 Mha of Forest Area in 2030.	4.2 - 4.5 Mha of Forest Area in 2030.

	2.3) Urban and settlements area	128,900 sq. km. as of 2015 urban land area	0.2% growth
	2.4) Protected areas	1249 protected areas, 30.2% of land, 19.4% of sea	By 2030, protected areas cover at least 30% of the land area and sea of the country
3. Productivity and management	**3.1)** Crop productivity for the key crops	As of 2022, agricultural productivity: Sugar beet (excluding seed): 42.91 tonne/ha; Potatoes (including seed potatoes): 26.45 tonne/ha; Grain maize and corn-cob-mix: 19.75 tonne/ha; Rice: 5.74 tonne/ha; Wheat and spelt: 2.72 tonne/ha; Barley: 2.44 tonne/ha Rye and winter cereal mixtures (maslin): 1.76 tonne/ha; Tobacco: 1.43 tonne/ha; Cotton fibre: 1.29 tonne/ha; Oats: 1.18 tonne/ha	Converge to EU average in crop yields for main crops: Cereals, Rice, Olives, Citrus fruits, Nuts. Green maize: 3.5 tn/ha, Wheat & Spelt: 4 tn/ha; Barley: 4 tn/ha, Cotton Fibre 1.5 tn/ha, Oats 3.5 tn/ha, Rye: 3.5 tn/ha
	3.2) Cropland under agroecological practices	Area under organic farming as of 2020, 10.2% of utilized agricultural area	20% or above by 2050
	3.3) Livestock productivity for the key livestock products	As of 2019, livestock production: Bovine: 231.8 Kg/ head Sheep and goat: 11.3 Kg/ head Pig: 67.7 Kg/ head Chicken Meat: 1.7 Kg/head Cattle Milk: 7.6 Kg/head Goat Milk: 1.4 Kg/head Hen Eggs: 180 Eggs/head	>200 Hen Eggs and double the yield for Cattle Milk, Goat Milk, Pig Meat and Goat & Sheep Meat

	3.4) Pasture stocking rate	Minimum stocking density levels for pastureland (which are set at 0.2 LU/ha for all categories of animal)	Maintain stocking rate around current levels
	3.5) Forest management	Permanent deforestation halted. Forests in continual deterioration due to poor management, competitive agricultural and settlement uses, intense pasture and summer fires. High slopes make harvesting extremely difficult, occurring only during May – Sept. when climatic conditions are favorable but this is an inappropriate period.	By 2030, promote the implementation of sustainable management of all types of forests, halt all deforestation, increase thinning and pruning as preventive measures and increase forest sector contribution to GDP from 0.05% to the EU average of 0.2%
4. Trade	**4.1)** Share of consumption which is imported for key imported products (%)	8.5 - 10 billion yearly imports of agricultural products	Reduction in order to achieve neutral agricultural trade balance
	4.2) Evolution of exports for key exported products (1000 tons)	6 - 7 billion yearly agricultural exports 2010 - 2020 - 9~10% of total exports (goods and services)	Increase in order to achieve neutral agricultural trade balance

5. Food	**5.1)** Average dietary composition	Average dietary energy supply, 2019-2021: 3412 kcal / capita/ day, of which, as per 2019: cereals: 811 kcal / capita/ day; fats and oils: 842 kcal / capita/ day; meat: 290 kcal / capita/ day; sugar: 332 kcal / capita/ day; roots, tubers and pulses: 118 kcal / capita/ day; fruit and vegetables: 287 kcal / capita/ day; dairy and eggs (exl. butter) 430 kcal / capita/ day; beverages and other: 189 kcal / capita/ day; fish and seafood: 38 kcal / capita/ day.	Diet shifts to the Lancet diet by 2050 (EAT, Planetary Health diet)
	5.2) Share of food consumption which is wasted at household level	As per 2019, the total per capita food waste generation in Greece is estimated to be 76.1 kg/inh-y.	Reduce food waste by 30% by 2035 and to relative EU median levels by 2050
6. Biofuels	**6.1)** Targets on biofuel and/or other bioenergy use	The projection of 2030 predicts that the bioethanol share will fall to 71%, the biodiesel will also fall to 12%, but BTL (biomass to liquids) will emerge and stand to 12% market share, especially due to second and third generation biofuels.	Greece plans to increase the RES-T to 19% in 2030 (10% without multipliers) with biofuels accounting for 80% of the RES-T or about 371 ktoe (vs. 157 ktoe in 2018). Contribution from biofuels from Annex IX-A feedstocks is expected to reach 197 ktoe in 2030 (vs. 0 ktoe in 2018). Greece has introduced a target for advanced biofuels of 0.2% in volume.
	6.2) Targets on other non-food use	-	The contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material shall be twice that made by other biofuels
7. Water	**7.1)** Irrigated crop area	Over the period 2011 - 2018, 36% of the agricultural area was irrigated.	Greece's target is to improve water management on 17.5% of agricultural land and water efficiency for 5% of irrigated land through irrigation infrastructure

Appendix II: Supplementary Figures & Tables

Figure A1: Most Produced Commodities in Greece

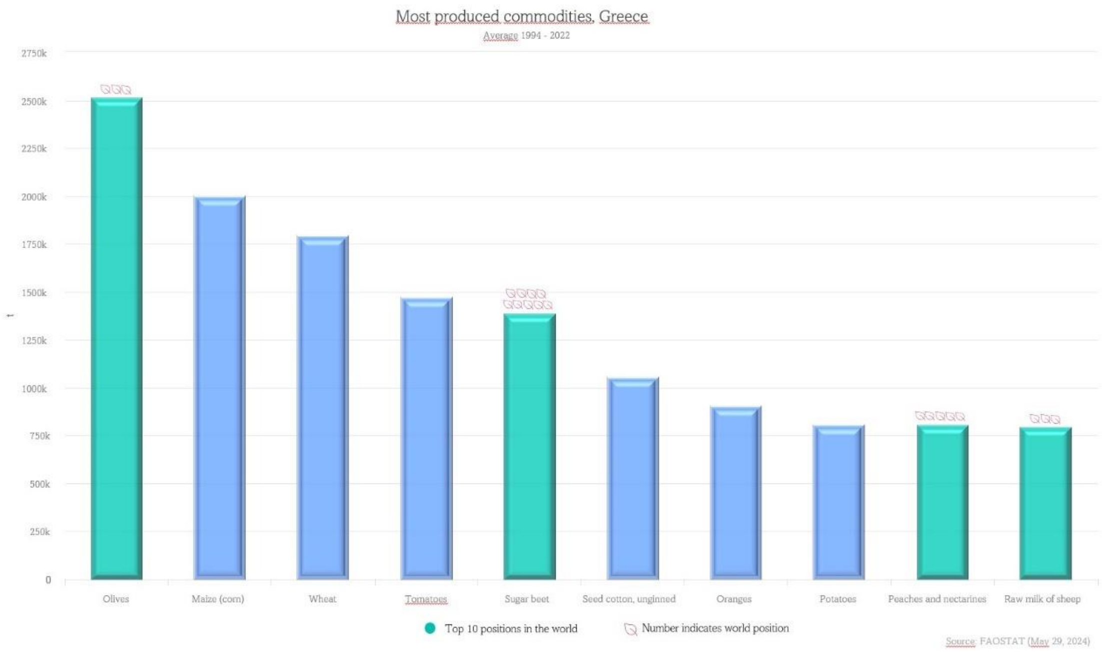

Table A3: Precision Agriculture Technologies for Crop Productivity

Technology	Description	Applications
Geographic Information Systems and Global Positioning System	GIS and GPS provide detailed mapping and geospatial data for precise field management and navigation.	Field mapping, soil sampling, yield mapping, and precision planting
Drones and Remote Sensing	Drones and remote sensing technologies capture high-resolution images and data for crop monitoring.	Crop scouting, disease detection, and monitoring crop health and growth
Soil and Plant Sensors	Sensors measure soil moisture, nutrient levels, and plant health for informed decision-making.	Irrigation management, nutrient management, and real-time monitoring of crops

Table A4: Precision Agriculture Technologies for Livestock Productivity

Technology	Description	Applications
Electronic Identification and GPS Tracking Systems	These systems enable precise tracking and identification of livestock, improving management efficiency.	Animal tracking, behavior monitoring, and pasture management
Automated Feeding and Milking Systems	Automation of feeding and milking processes to enhance efficiency and productivity.	Automated feeding schedules, milking operations, and improved production rates
Health Monitoring Sensors	Sensors monitor vital health parameters of livestock, aiding in early disease detection and management.	Health monitoring, disease prevention, and improving animal welfare