Greenhouse gas emissions in Greek agriculture: trends and projections

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Abstract. The objective of this research is to provide a comprehensive analysis of Greenhouse Gas (GHG) emissions from the agriculture sector in Greece, focusing on the assessment of historical trends and future projections. The study will put under scrutiny the principal contributors to these emissions, including enteric fermentation, manure management, rice cultivation, and agricultural soils. Additionally, it will identify the key drivers behind these emissions, such as livestock population and fertilizer use. Using methods of the Intergovernmental Panel on Climate Change (IPCC), the paper will project future emission levels. Finally, it will propose evidence-based mitigation strategies and policy recommendations to help Greece transition towards a more sustainable and climate-resilient agriculture sector.

1 Introduction

Global warming consists one of the main challenges of world since it is altering the climate conditions and weather patterns and is expected to have far-reaching, long-lasting and, in many cases, devastating consequences for the planet. According to WMO, the global average temperature has increased by 1.1 ℃ since the preindustrial period, and by 0.2 ℃ compared to 2011–2015; and 2019 concluded a decade of exceptional global heat, retreating ice and record sea levels driven by greenhouse gases produced by human activities [1, 2, 3].

The emergency to avoid dangerous climate change by limiting GHG emissions and reaching a carbon neutral world has led to the first-ever universal, legally binding climate change agreement in Paris in December 2015. The Paris Agreement's long-term temperature goal is to limit the increase of global temperature to well below 2oC above pre-industrial levels; and to pursue efforts to limit the increase to 1.5 C, recognizing that this would substantially reduce the risks and impacts of climate change [1].

To adequately address this "climate emergency", World and Europe specifically needs urgently reduce greenhouse gases (GHG) emissions and adapt to the consequences of global warming, which we are already experiencing [1, 4, 5].

EU Member States are committed to a binding target of an at least 40% domestic reduction in greenhouse gas emissions by 2030 compared to 1990, to be fulfilled jointly, as set out in the conclusions by the European Council of October 2014. In December 2020, as part of the European Green Deal, EU leaders have agreed on a more ambitious goal for cutting greenhouse gases - reducing them by 55% by 2030, rather than 40% [6].

Several policies and measures have been adopted and much more are planned by the EU Members targeting on the GHG emission reduction, e.g. CO_2 emissions trading system (EU-ETS), legislation relevant to the aviation sector, several financing mechanisms and fiscal measures.

Not covered by the EU Emissions Trading Scheme (non-ETS) greenhouse gas (GHG) emissions reduction consists of one of the main targets for European Union for the next decades taking into account that they accounted as the 55 to 60% of the total GHG emissions. The European Council agreed in 2014 to reduce the EU's greenhouse gas emissions by at least 40% by 2030, as compared to its emissions in 1990. These emissions mainly result from energy, agricultural, transport and waste sectors [7]. However, the implementation of the European Union (EU) requirements to limit GHG emissions from sectors not covered by the EU Emissions Trading Scheme (non-ETS) have implications to state development [7].

The accounting and reporting of the GHG emissions reductions has many benefits for decision makers, including international organizations, national and local authorities, public and private companies, etc. Among others, it promotes decision making by assisting the selection of informed policy choices that move toward low carbon development; it assists the justification of budget allocation to mitigation actions, and climate finance for developing countries; it facilitates public awareness and broader acceptance and support by all stakeholders; it increases the reliability of the climate change mitigation policies; it constitutes the feedback

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mechanism of the policy appraisal and evaluation cycle that allows the periodic performance tracking and assessment of the effectiveness of these policies and actions [8, 9].

Strategies for mitigation and adaptation, along with their corresponding action plans, are not solely confined to the realm of climate change. They are equally applicable to a variety of potential hazards, including but not limited to industrial safety [10]. The primary objective of these strategies is to lower risk and bolster resilience in the face of possible threats. By employing these strategies and formulating effective action plans, organizations can actively control risks and minimize the detrimental impacts arising from potential hazards. In a broader sense, mitigation and adaptation strategies serve as a structural guideline for devising efficacious action agendas tailored to a spectrum of potential hazards, inclusive of those associated with industrial safety [11].

Focusing in the Agricultural sector, several works have presented for the effective monitoring of GHG emissions and on the development of tools for the projection of the emissions for the future. As Pilvere et al. [12] explained, the agricultural modelling world has generated several models aiming at the analysis of the response of the sector to certain changes in exogenous mainly policy variables.

Rivza et al. [13] presented a methodology for the assessing agricultural production forecasts in Latvia with regard to the outcome of GHG emissions. As they explained, the developed model may be used as a decision support tool for impact assessment of various measures to reduce emissions and for seeking solutions to GHG emission mitigation by agricultural policy decisions. Moore et al. [14] concluded that disaggregating national estimates to the farm resource region level can help to inform and prioritize programs and policies consistent with existing climate goals. Pilvere et al. [12] shown that it is important to have Value Added indicator in agricultural policy simulation tools in order to identify the potential development of this sector.

In the framework of this paper, a comprehensive analysis of GHG emissions from the agriculture sector in Greece, focusing on the assessment of historical trends and future projections, is performed, while an evidence-based mitigation strategies and policy recommendations to help Greece transition towards a more sustainable and climate-resilient agriculture sector is presented.

2 Methodology – GHG emissions estimation

According to the IPCC Guidelines, the following source categories are included in this sector:

- Enteric fermentation
- Manure management
- Rice cultivation
- Agricultural soils
- Field burning of agricultural residues

The calculation of GHG emissions from Agriculture is based on the methodologies and emission factors suggested by the 2006 IPCC Guidelines, Tier 2 approaches [15]. Data on animal population, agricultural production and cultivated areas used for the emissions calculation will be collected by the Hellenic Statistical Authority (ELSTAT), while data on the amounts of synthetic fertilizers applied to soils derive from Pan-Hellenic Association of Professional Fertilizers Producers & Dealers.

2.1 Enteric Fermentation

Methane is produced during the normal digestion of food by herbivorous animals and the amount emitted depends on the animal species, their digestive system and feed intake.

Tier 2 methodology is applied for the estimation of methane emissions from enteric fermentation of cattle and sheep, according to the IPCC Guidelines. Net energy required for animal maintenance, for animal activity, for lactation, for pregnancy and energy for growth are taken into account. Data relevant to average bodyweight, average milk production, weight gain for young etc are based on country specific data based on Greek Expert judgements.

Methane emissions from enteric fermentation for the other animals are estimated according to the Tier 1 IPCC methodology.

2.2 Manure management

Manure management is responsible for methane and nitrous oxide emissions. Methane is produced during the anaerobic decomposition of manure, while nitrous oxide is produced during the storage and treatment of manure before its use as fertilizer. The shares of manure management systems per animal species are presented in Table 1 considering 100% conditions of temperate climate region for Greece. Country-specific data for all the animal categories have been considered

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Table 1. Setting Word’s margins.

Manure management systems	Liquid systems	Daily spread	Solid storage and dry lot	Pasture/ range/ paddock
Dairy cows	5.5	0	86.5	8
Other cattle	0	3	64	33
Buffalo	0	3	64	33
Poultry	0	0	100	0
Sheep	0	0	10	90

Swine	90	0	10	0
Horses	0	0	0	100

CH_4 emissions from manure management were estimated using IPCC Tier 2 approach for dairy cattle and other cattle and sheep. For the rest of the animals T1 methodology is used. In order to calculate N_2O emissions from manure management, the default IPCC methodology was used.

2.3 Rice cultivated

Rice cultivated in Greece is grown in continuously flooded fields. This process results in methane production from anaerobic decomposition of organic matter, and consequently leads to the release of the gas in the atmosphere through the rice plants. In order to estimate methane emissions from rice cultivation, the T1 methodology suggested by the IPCC guidelines was followed. Rice cultivated in Greece is grown in continuously flooded fields without the use of organic amendments and one cropping period is considered annually.

2.4 Agricultural soils

Agricultural soils constitute the largest anthropogenic source of nitrous oxide emissions. N_2O is produced naturally in soils through the microbial processes of nitrification and denitrification. Agricultural activities add nitrogen to soils, increasing the amount of N_2O released in the atmosphere. Anthropogenic N_2O emissions from agriculture are produced either directly from nitrogen inputs to soils or indirectly, after the removal of nitrogen from soils. The N_2O emissions sources examined are the following:

- Direct N_2O emissions
- Indirect N_2O emissions

For the estimation of N_2O emissions from Agricultural soils, the default IPCC methodology was used.

2.5 Field burning of agricultural residues

The generation of crop residues is a result of the farming practices used. Disposal practices for residues include ploughing them back into the ground, composting, landfilling and burning on-site. It is considered that the residues burned annually on the field comes from the 5% of total cultivated area in Greece. Burning of agricultural residues is responsible for emissions of CH_4, N_2O, CO and NOx.

For the estimation of CH_4 and N_2O emissions from field burning of agricultural residues the default methodology by IPCC 2006 Guidelines has been applied.

2.6 Urea application

Adding urea to soils during fertilisation leads to a loss of CO_2 that was fixed in the industrial production process. Urea ($CO(NH_2)_2$) is converted into ammonium (NH_4+), hydroxyl ion (OH-), and bicarbonate (HCO_3-), in the presence of water and urease enzymes. Similar to the soil reaction following addition of lime, bicarbonate that is formed evolves into CO_2 and water.

For the estimation of CO_2 emissions from Urea application the default methodology suggested in IPCC Guidelines has been applied. The emission factors used are the default ones suggested by IPCC Guidelines.

3 Methodology – Policies and Measure

3.1 Policies

Agriculture sector is mainly driven by one policy, the Common Agricultural Policy (CAP), which determines a common way for all Member States of the European Union [16]. For the period 2014 – 2020, three strategic objectives for rural development in the EU have been set in line with the Europe 2020 Strategy: Improving the competitiveness of agriculture, the sustainable management of natural resources and climate action, and a balanced territorial development of rural areas. The legislative framework concerning the rules for agriculture production in Greece is fully harmonized with the European Common Agricultural Policy (CAP) [17].

In addition to the CAP, the Rural Development Programme (RDP) focuses mainly on enhancing farm viability and competitiveness, preserving and enhancing ecosystems and promoting local development in rural areas. Farmers receive support to preserve biodiversity, o improve water management and to improve soil management and/or prevent soil erosion.

Rural Development Policy's actions that contribute directly to the decrease of greenhouse gas emissions are the following:

- Organic farming.
- Decrease of the use of synthetic nitrogen fertilizers.
- Disengagement of subsidies from the agricultural production (reduction of the rate of intensity of agricultural land use).
- Use of environment-friendly livestock farming methods and improvement of the management of animal waste.
- Improvement of energy efficiency, renewable energy generation and use, including biomass.
- Improve management of soil (maintenance of agricultural activities in mountainous areas, green cover, and permanent grassland) and increase carbon sequestration.

3.2 Projections

For the projections of emissions for the next years, the development of main determinant parameters is based on the historical data trend analysis, on the expected gross value added of agriculture (GVA) evolution, the listing of the adopted policies and measures and the analysis of the impact of the already implemented measures on the GHG emissions for the previous years.

The main determinant parameters of GHG emissions from agriculture are the animal population, the quantities of synthetic nitrogen fertilizers applied on soils and the agricultural crops production.

Regarding the animal population, the rate of change of population of each animal category is estimated based on the analysis of the expected GVA evolution for the next decades.

The decrease in the use of synthetic nitrogen fertilizers for the period 2010-2020 could probably be attributed to the mitigation measures and to the effect of the economic crisis, while for the period 2020-2040 an increase in the use of synthetic nitrogen fertilizer is foreseen as the result of the anticipated economic recovery despite the impact of the mitigation measures. Data for the period 1990-2021 derive from the Pan-Hellenic Association of Professional Fertilizers Producers & Dealers (PHAPFPD), while the projections are based on the analysis of the trends observed in the whole period 1990-2021.

Finally, for the projection of agricultural crops production, similarly with the animal population, an analysis based on the expected GDP evolution for the next decades, was performed.

4 Results and discussion

GHG emissions from Agriculture decreased by 23.6% between 1990 and 2021 (see Fig. 1), with an average annual rate of decrease of 0.76. The steep decrease observed for the years 1993 and 1994 is due to the cut backs in public incentives for the use of synthetic fertilizers.

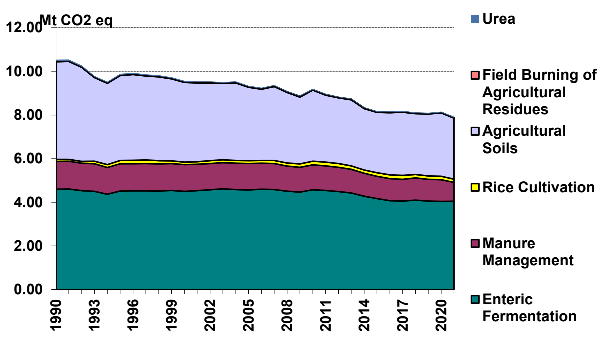

Fig. 1. GHGs emissions per sub sector from Agriculture

Emissions from Agriculture and especially N_2O emissions from agricultural soils are characterized by intense fluctuations during the period 1990 – 2021. The annual variations of agricultural production and the amount of synthetic fertilizers applied are the main causes for these fluctuations.

Methane emissions from enteric fermentation in 2021 account for 50.4% of total GHG emissions from Agriculture. The average annual rate of decrease of emissions from enteric fermentation for the period 1990 – 2021, is estimated at 0.39% (decrease by 12.0% in 2021 compared to 1990).

CH_4 and N_2O from manure management in 2021 accounted for 9.1% and 3.3% of total GHG emissions from Agriculture respectively. CH_4 emissions in 2021 decreased by 22.4% compared to 1990 levels, with an average annual rate of decrease estimated at 0.7% for the period 1990 – 2021. N_2O emissions in 2021 decreased by 20.9% compared to 1990 levels, with an average annual rate of decrease estimated at 0.7%.

CH_4 emissions from rice cultivation in 2021 account for 1.85% of total GHG emissions from Agriculture. CH_4 emissions increased by 61.5 % in 2021 compared to 1990, with an average annual rate of increase of 2.0% for the period 1990 – 2021.

The fluctuations in emissions trends are attributed to the annual changes in the amount of the cultivated areas as provided by the EL.STAT.

The reduction of N_2O emissions from agricultural soils is mainly due to the reduction in the use of synthetic nitrogen fertilizers. The decrease in the use of synthetic nitrogen fertilizers could probably be attributed to an increase in non fertilized farming, the price of fertilizer and the impact of initiatives to promote good practice in fertilizer use. Additionally, the annual changes in the amounts of fertilizers used and the agricultural production are the basic factors that account for the fluctuation of emissions during the period 1990 – 2021.

For the projection of the emissions for the period up to 2040, as explained in methodology Chapter, Gross added Value (GVA) for agriculture was used a driven parameter, taking into account the impact of adopted and the planned policies and measures. For the applicability of aforementioned methodology, the historical data relevant to the Gross Added Value (GVA), the Cattle population and the nitrogen fertilizers consumption are presented in Fig. 2. As it is shown, similar decreasing trend is observed for the GVA and the cattle population, while for the nitrogen fertilizers the decreasing trend is steeper due to the policies and measures concern the enhance of organic cultivation and the reduction on the nitrogen fertilizers consumption. To be noted that similar trend with cattle is observed for most of the other animal species.

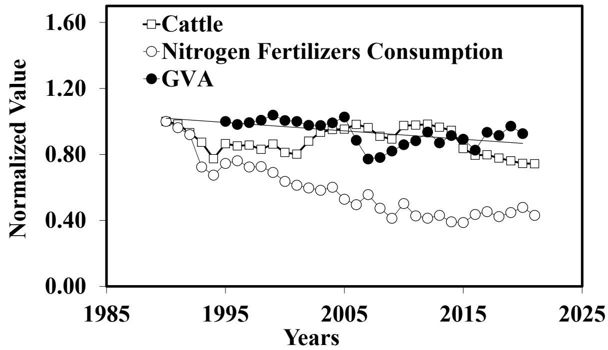

Fig. 2. Normalized Gross Added Value (GVA) versus normalized Cattle population and nitrogen fertilizers consumption (Historical Data)

Having calculated the activity data for the period up to 2040, the methodologies developed for the GHG emissions calculation for the period 1990-2021, were used for the projection of the emissions for the period up to 2040, and they are shown in Fig. 3. As it is presented an increase in emissions from the agriculture sector is foreseen as a consequence of anticipated economic recovery. However, said increasing trend is smoother than the increase of the GVA, as it is shown in Figure 3, due to the mitigation measures already adopted and affect Agricultural Sector.

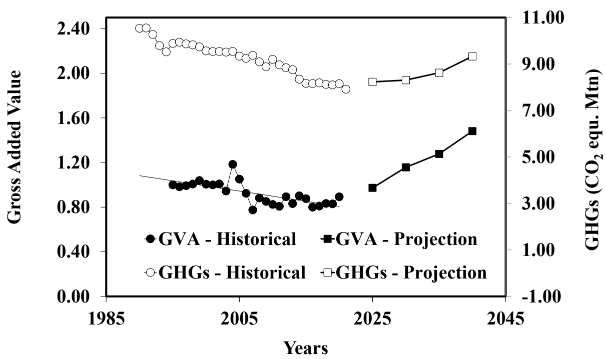

Fig. 3. Normalized Gross Added Value (GVA) vs GHG emissions (Historical and Future Projection Data)

Although, as per Fig. 3, the impact of the policies and measures is expected to affect the evolution of the GHG emissions for the next decades, it is considered that there is room for extra GHG emission reduction by adopting more targeting measures.

The optimization of the animal waste management procedures could offer significantly on the aforementioned target, taking into consideration the data presented in Table 1. As it is shown, manure for animal species like, poultry and cattle, present potential for improved treatment methodologies than this of simple solid storage resulting in reduced methane emissions.

In addition to the improved manure treatment, the anaerobic treatment of animal's manure, e.g., from poultry, for power generation could affect both on the direct reduction of GHG emissions and the power generation, offering in indirectly GHG emission reduction due to the reduction on the relevant fossil fuels consumption for power generation.

Finally, actions concern the further reduction of the use of synthetic fertilizers could more contribute on the target of GHG emissions reduction. Through financing measures, and awareness and information actions Greece could in local and EU framework enhances more the actions of nitrogen fertilizers consumption affecting significantly the final GHG emissions, taking into account that the synthetic nitrogen fertilizers is the main source of GHG emissions from Agriculture for Greece.

The robustness of our research is grounded in the application of the 2006 Guidelines for National Greenhouse Gas Inventories from IPCC, ensuring the credibility of our GHG emissions estimations. In the absence of comparable studies, our unique methodology further stands out through its use of historical data and Gross Value Added (GVA) projections for predicting future emissions. By accounting for both enacted and future planned policies in the agricultural sector, our approach offers a comprehensive and realistic view, affirming the reliability of our results, even in the face of scarce similar research.

5 Conclusions

The development of monitoring systems and the quantification of the effect of policies and measures to mitigate climate change are very useful exercise that can be used to meet a variety of objectives, such as informing policy design, enhancing policy implementation, assessing policy effectiveness, justifying budget allocation to mitigation actions, and attracting climate finance.

The proposed methodological framework for the projection of the GHG emissions from agriculture based on the evolution of economical parameters and more specifically on Gross Added Value of Agriculture, which was presented in this paper, could contribute to the ongoing debate on how to achieve a low-carbon and sustainable food system in the Mediterranean region.

Although, the impact of the policies and measures is expected to affect the evolution of the GHG emissions for the next decades, it is considered that there is room for extra GHG emission reduction adopting more targeting measures. Actions like the optimization of the animal waste management procedures, the utilization of manure for power generation through anaerobic treatment and the further reduction of the use of synthetic fertilizers are recommendations that can help Greece transition towards a more sustainable and climate-resilient agriculture sector.

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