Methodological Framework for the Quantification of GHG Emission Reductions from Climate Change Mitigation Actions

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Abstract

The quantification of the effect of climate change mitigation actions is a 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, and attracting climate finance. It is also a reporting requirement according to the reporting framework of the United Nations Framework Convention on Climate Change (UNFCCC) and the Monitoring Mechanism Regulation of the European Union (EU) about climate change relevant information. However, the reporting of emissions savings associated to mitigation actions by EU Member States is not complete, according to recent technical reports of the European Environmental Agency. The purpose of this paper is to present a methodological framework that can be used to quantify the effect (i.e. emission reductions) of the mitigation actions. It is based on comprehensive and transparent models and formulas that could be easily tracked and reproduced. The proposed framework could be easily applied by EU Member States, but also by other non-EU

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countries, to enhance the reporting of climate change related information to European Commission and UN bodies. By applying the methodological framework for Greece, as a case study, it was possible to estimate the effect of implemented policies and measures for historical years (ex-post analysis), but also to estimate the projected effect (ex-ante analysis) of implemented, adopted and planned policies for future years (e.g. 2030).

Keywords: Climate change, greenhouse gas emissions, mitigation actions, assessment of the effect of policies and measures.

1 Introduction

Climate change poses a major challenge and threat to the places, species and people's livelihoods. Increased levels of atmospheric greenhouse gases impact earth's heat balance, leading to global warming. Global warming 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, e.g. glaciers are melting, sea levels are rising, weather is getting more extreme, and some ecosystems are at risk of collapsing. According to WMO, the global average temperature has increased by 1.1°C since the pre-industrial period, and by 0.2°C 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. To adequately address this "climate emergency", we need urgently reduce greenhouse gases (GHG) emissions and adapt to the consequences of global warming, which we are already experiencing [1, 2].

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 2°C 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. This should be done by peaking emissions as soon as possible, in order to "achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases" in the second half of the 21st century [3, 4].

Climate change mitigation refers to the reduction of the release of anthropogenic GHG in order to limit the magnitude or rate of global warming and its related effects. Mitigation may also be achieved by increasing the capacity of carbon sinks, for example through reforestation. Examples of mitigation actions include retrofitting buildings to make them more energy efficient, phasing out fossil fuels by adopting renewable energy sources like solar, wind and small hydro. Mitigation actions can be deployed in all sectors of the economy i.e. power sector, industry, transport, buildings, agriculture, waste, etc [5–9]. Governments in both developed and developing countries are planning and implementing a variety of mitigation actions that can be written down in national environmental policy documents of countries, for instance the nationally determined contributions (NDC) under the Paris Agreement [3, 4].

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 mechanism of the policy appraisal and evaluation cycle that allows the periodic performance tracking and assessment of the effectiveness of these policies and actions [10].

According to the current reporting framework to the United Nations Framework Convention on Climate Change (UNFCCC), countries are required to include information about the quantification of the effect of policies and measures for the mitigation of GHG emissions in their reporting to the UNFCCC. More specifically, according to the reporting guidelines for National Communication of Parties included in Annex I of the Convention (developed countries), Parties are required to report an ex-post and ex-ante assessment of the aggregate effects of policies and measures, and should include a quantitative estimate of the impacts of individual policies and measures or as a group [11]. Further, according to the reporting guidelines for Biennial Reports for developed countries, an ex-ante assessment of mitigation actions is required to be reported every two tears [12]. Regarding the reporting requirements for developing countries, an estimation of emission reductions to the extent possible is required to be reported for each mitigation action [13]. Similar reporting provisions for all countries are included in the Enhanced Transparency Framework of the Paris Agreement [14].

In addition to the international reporting requirements, EU Member States are required to report every two years both ex-post and ex-ante quantitative estimates of the effect of mitigation policies and measures [15]. However, according to both the 2018 and 2019 technical reports of the European Environmental Agency that provide an overview of the reported information by the Member States about policies and measures on climate change mitigation [16, 17], "the reporting on ex-post emission savings should be considered as very incomplete" and the "expected emission savings (ex-ante assessment) are reported for less than 40% of total reported policies and measures".

The purpose of this paper is to present the methodological framework that has been developed and is currently applied by Greece for the ex-post and ex-ante analysis of the effect of national policies and measures on climate change mitigation. The methodological framework gains advantages and is consistent to available official information and reporting to European Commission and UN. Besides is based on comprehensive and transparent models and formulas that can be easily understood and reproduced. The proposed framework could be applied by EU Member States, but also by other countries, to enhance the reporting of climate change related information to European Commission and UN bodies.

2 Description of the Methodological Framework

2.1 Main Principles of the Framework

EU Member States have many reporting obligations to European Commission. These reporting obligations are related to the assessment of the implementation of EU Directives and Regulations. A main principle of the proposed framework is to be consistent with all available official information that is reported by Member States through the various reporting channels to European Commission and UN bodies. In addition to the consistency principle, the framework gains advantage of the reported information and avoids duplication of effort. The framework is based on the following information:

- The National GHG Inventory (data, methods, emission factors and parameters).
- The National Energy Balance.
- The National Future Energy Planning Scenarios.
- The National Energy Efficiency Action Plans and Annual Reports that are required to be reported to the European Commission pursuant to the Energy Efficiency Directive (EED) [18].
- The National Action Plans and Progress Reports that are required to be reported to the European Commission pursuant to the Renewable Energy Directive (RED) [19].

- The National Energy and Climate Plans that are recently prepared by EU Member States pursuant to Regulation EU) 2018/1999 [20].
- The targets, policies and reporting under the Directives and Regulations associated to fluorinated gases, agriculture and waste sectors (e.g. F-gas Regulation, Common Agricultural Policy, Landfill Directive).

The proposed framework is based on models and formulas that could be easily understood and reproduced. Consequently, it contributes to the enhancement of the transparency of the reported information, which is a fundamental principle under the current reporting framework of UNFCCC and the Paris Agreement [14] and serves the building of mutual trust and confidence between the countries.

For consistency reasons, the same methods are applied for both the ex-post and ex-ante analysis for the estimation of emissions reductions. Therefore, the estimated effect of mitigation actions for the historical years is consistent and comparable with the projected effect for future years. Further, the framework is consistent with the reported projections of GHG emission scenarios to European Commission (EC) and UNFCCC. According to EC and UNFCCC reporting requirements, the countries have to report a "with existing measures" emissions projection scenario (WEM), which encompass currently implemented and adopted policies and measures; and it is to their discretion to report a "with additional measures" scenario (WAM), which additionally reflects the planned policies and measures.

Double counting of mitigation effects is avoided, because all possible interferences between implemented/adopted and planned measures are taken into account and the analysis is performed at a fairly high level of aggregation, and not at the level of each individual instrument and program. For example, the promotion of renewable energy sources (RES) by a country is implemented through many instruments, e.g. the Feed-in-Tariff system, the Feed-in-Premium system, national development laws, tax incentives etc. The analysis provides a single mitigation effect per emission source / activity (i.e. power sector, road transport sector, etc) for the group of these instruments, since it is neither possible nor meaningful to distinguish the impacts of individual instruments and programs that focus on the same emissions source or activity.

The main idea of the framework, behind the estimation of the mitigation effect, is to compare the historical emissions (for the ex-post analysis) and the WEM/WAM scenarios (for the ex-ante analysis) with a hypothetical without measures baseline scenario (WOM), which covers only the emission

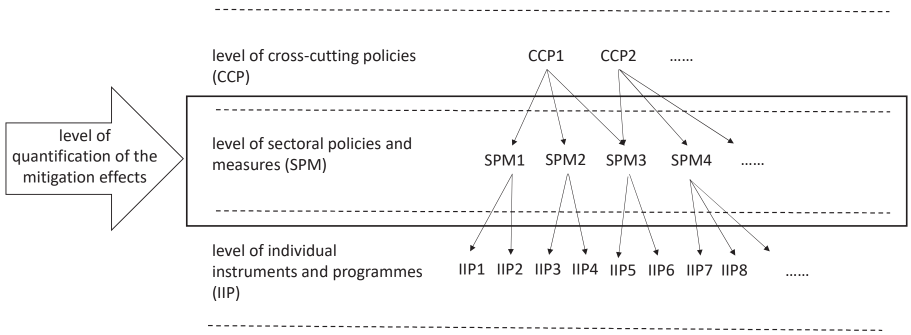


Figure 1 Graphical presentation of the different levels of mitigation actions.

source/activity under investigation and does not include the mitigation effect of the examined policy or measure. Further, the estimation of mitigation effects focuses on sectoral policies and measures with a direct – quantifiable mitigation impact that target individual emission sources and activities. The effect of overarching and cross-cutting supporting policies for the restriction of GHG emissions is not reported, because it has been already included to the effect of sectoral measures. By this way double counting is avoided. Figure 1 illustrates the different levels of policies and measures (cross-cutting, sectoral, and individual instruments) and graphically explains at which level of aggregation the mitigation effects are estimated by the framework. For example, a significant over-arching policy is the EU Emission Trading Scheme (EU ETS). The effect of EU-ETS is not reported, because it is included under the effect of a number of sectoral measures, e.g. the promotion of RES, the improvements in the conventional power generation system, the promotion of natural gas in industry, etc. In this case, the cost of emission allowances under the EU ETS is the incentive to implement measures to reduce emissions through e.g. shifting to low carbon fuels, RES and energy efficiency measures. The effect of the shift to low carbon fuels, implementation of RES and energy efficiency measures is quantified, and is reported under the specific sectoral measures.

2.2 Sectoral Policies and Measures

In this section, the methods for the quantification of the emissions reductions by the implementation of the following mitigation actions will be presented:

- RES technologies in electricity production.

- Improvements in the conventional power generation system.
- Promotion of natural gas (residential, tertiary, industrial and transport sectors).
- Biofuel use in transportation.
- Implementation of energy efficiency measures in residential, tertiary and transport sectors.
- Mitigation actions in waste sector (e.g. recovery of organic waste and recycling, recovery of biogas).
- Reduction of emissions of fluorinated gases.
- Mitigation actions in agriculture (e.g. reduction of the rate of intensity of agricultural land use, increase of organic farming, reduction in fertilizers use).

For the ex-ante assessment of the implemented and adopted policies and measures, data included in the WEM projection scenario should be used, while for planned policies and measures the WAM scenario should be selected.

2.2.1 RES technologies in electricity production

The production of electricity by RES (e.g. wind, solar PVs, hydro, geothermal, biomass and biogas) does not result in emissions, with the exception of biomass and biogas that result in CO2 emissions and small amounts of CH4 and N2O. However, biomass and biogas are considered a carbon-neutral fuel, because the plants that are the source of biomass capture almost the same amount of CO2 through photosynthesis while growing as is released when biomass is burned. The avoided GHG emissions correspond to the emissions associated to the production of the same amount of electricity by using fossil fuels. The data required for the estimation is the electricity produced by RES, which can be obtained from the national energy balance for the ex-post analysis and the WEM/WAM scenarios for the ex-ante analysis. In addition, the average emission factor (EF) of the thermal power plants is required. This can be calculated by using emissions and electricity production data from the national inventory, the national energy balance and the WEM/WAM scenarios. The mitigation effect is calculated by the following formula:

$$mitigation\ effect = \left(electricity_{RES,t} - electricity_{RES,t_0}\right) \times EF_{th.plants,t}/1000,$$

where:

mitigation effect is estimated in ktCO2eq,

$\text{electricity}_{\text{RES,t}}$ is the amount of electricity produced by RES in year t (units: GWh),
t_0 is the starting year of promoting the RES technologies, and
$\text{EF}_{\text{th.plants,t}}$ is the average emission factor of the thermal plants of the electricity generation system in year t (units tCO2eq/GWh).

The average EF of the thermal plants varies annually depending on the energy mix of the fossil fuels of each year. Consequently, the effect of this policy is separated from the respective effect of the mitigation actions that are related to the increase of the efficiency of power plants and switching to low carbon fossil fuels (double counting is avoided).

2.2.2 Improvements in the conventional power generation system

This policy refers to the gradual decommissioning of old inefficient thermal power units, the commissioning of new efficient power units, and the increase of the share of natural gas (a low carbon fuel) in electricity production. The avoided GHG emissions relate to the lower emissions per electricity produced by the more efficient newer plants compared to the old ones; and the lower carbon content of natural gas compared to solid fuels. The data required for the estimation is the electricity produced by solid fuels and natural gas, which can be obtained from the national energy balance for the ex-post analysis and the WEM/WAM scenarios for the ex-ante analysis. In addition, the average emission factors (EF) of the thermal power plants per fuel are required. These can be calculated by using emissions and electricity production data from the national inventory, the national energy balance and the WEM/WAM scenario. The mitigation effect of the decommissioning of old plants and the commissioning of new more efficient ones is calculated by the following formula:

$$mitigation\ effect = electricity_{solid\ fuels,t} \times \left(EF_{solid\ fuels,t} - EF_{solid\ fuels,t_0}\right)/1000,$$

where:

mitigation effect is estimated in ktCO2eq,
$\text{electricity}_{\text{solid fuels,t}}$ is the amount of electricity produced by solid fuels-fired plants in year t (units: GWh),
t_0 is a reference year before the replacement of old units, and

$EF_{solid\ fuels,t}$ is the average emission factor of the solid fuels-fired thermal plants of the electricity generation system in year t (units tCO2eq/GWh).

The mitigation effect of the shift to natural gas is calculated by the following formula:

$$mitigation\ effect = electricity_{NG,t} \times \left(EF_{solid/liquid\ fuels,t} - EF_{NG,t}\right)/1000,$$

where:

mitigation effect is estimated in ktCO2eq,
$electricity_{NG,t}$ is the amount of electricity produced by gas-fired plants in year t (units: GWh),
$EF_{solid/liquid\ fuels,t}$ is the average emission factor of the solid and liquid fuels-fired thermal plants of the electricity generation system in year t (units tCO2eq/GWh), and
$EF_{NG,t}$ is the average emission factor of the gas-fired thermal plants of the electricity generation system in year t (units tCO2eq/GWh).

The EFs used in the model vary annually depending on energy efficiency level of the thermal plants for each year.

2.2.3 Increase of natural gas share in industry, transport, residential and tertiary sectors

This policy is related to economic, fiscal, regulatory and other instruments (e.g. information campaigns) for the promotion of the use of natural gas by end users (industry, residential, transport and tertiary sectors). The change from solid and liquid fuels (e.g. coal, fuel oil, etc) to low carbon fuels (e.g. natural gas) results in reduction of GHG emissions. The avoided GHG emissions correspond to the lower carbon content of natural gas compared to solid and liquid fuels. The data required for the estimation is the amount of natural gas, which can be obtained from the national energy balance for the ex-post analysis and the WEM/WAM scenarios for the ex-ante analysis; and the CO2 emission factors of natural gas and the fuel that is substituted (source: national GHG inventory). The mitigation effect is calculated by the following formula:

$$mitigation\ effect = activity\ data_{NG} \times \left(EF_{fuel} - EF_{NG}\right)/1000,$$

where:

mitigation effect is estimated in ktCO2eq,
activity $data_{NG}$ is the amount of natural gas that is combusted (units: TJ),
EF_{fuel} is the CO2 emission factor of the fuel that is substituted by natural gas (units: tCO2/TJ), and
EF_{NG} is the CO2 emission factor of natural gas (units: tCO2/TJ).

The above calculation of the mitigation effect is conservative, because the combustion efficiencies between the different fuels were not taken into account. For example, the combustion of natural gas, which is a gaseous fuel, is more efficient compared to solid fuels.

2.2.4 Biofuel use in transportation

When estimating the mitigation effect of the shift from fossil fuels to biofuels, it should be considered that a part of the carbon of biofuels (and the associated CO2 emissions) may have a fossil origin. For example, 5.3–5.5% of the carbon content of biodiesel (FAME) has a fossil origin. The remaining part of the carbon content is considered carbon-neutral because it has a biogenic origin. The avoided GHG emissions correspond to the lower fossil carbon content of biofuels (e.g. biodiesel, biogasoline, etc) compared to fossil liquid fuels. The data required for the estimation is the amount of biofuels, which can be obtained from the national energy balance for the ex-post analysis and the WEM/WAM scenarios for the ex-ante analysis; the CO2 emission factors of the fossil part of biofuels (source: national GHG inventory); and the CO2 emission factors of liquid fuels that are substituted by biofuels (e.g. diesel, gasoline, etc). The mitigation effect is calculated by the following formula:

$$mitigation\ effect = activity\ data_{biofuel} \times \left(EF_{liquid\ fuel} - EF_{biofuel}\right)/1000,$$

where:

mitigation effect is estimated in ktCO2eq,
activity data of biofuel consumption is in TJ units,
$EF_{liquid\ fuel}$ is the CO2 emission factor of the liquid fuels that are substituted by biofuels (units: tCO2/TJ), and
$EF_{biofuel}$ is the CO2 emissions factor of the fossil part of biofuels (units: tCO2/TJ).

2.2.5 National Energy Efficiency Action Plans (NEEAPs)

The National Energy Efficiency Action Plans of EU Member States contain several measures that are related to the conservation and rational use of energy in the residential, tertiary and transport sectors. These measures are related to actions for the improvement of the thermal behavior of residential sector buildings; promotion of energy efficiency appliances and heating equipment, renewal of the vehicle fleet through deployment of clean and efficient vehicles, etc. Under the Energy Efficiency Directive, EU Member States shall draw up these plans every three years and also provide annual reports. The energy savings per measure should be estimated and reported by Member States. Therefore, the activity data required for the estimation of the mitigation effect of energy efficiency measures are available in these reports. In addition, the CO2 emission factors for electricity, gaseous, liquid and solid fuels can be obtained from the national GHG inventory. The mitigation effect is calculated by the following formula:

$$mitigation\ effect = energy\ savings_{fuel} \times EF_{fuel}/1000 + energy\ savings_{el} \times EF_{el}/1000,$$

where:

mitigation effect is estimated in ktCO2eq,
energy $savings_{\mathrm{fuel}}$ is the estimated savings of gaseous, liquid or solid fuels in TJ,
energy $savings_{\mathrm{el}}$ is the estimated savings of electricity GWh units,
EF_{fuel} is the CO2 emission factor of the gaseous, liquid or solid fuels (units: tCO2/TJ), and
EF_{el} is the average emission factor of the electricity generation system of the country (units: tCO2eq/GWh).

2.2.6 Reduction of emissions of fluorinated gases

To control emissions from fluorinated greenhouse gases (F-gases), the main legislative act in the European Union is the ‘F-gas Regulation’ (No 517/2014). This Regulation covers all key applications in which fluorinated gases are used. Its objective is to prevent leakage and emissions (emissions prevention and leak checks, control of by-production, end of life treatment of products and equipment, training and qualification, information for users, labelling, product information) and control the use of F-gases with high global warming potential (ban on new applications, ban on uses, phase-down of HFC supply) [29].

For the estimation of the mitigation effect of the measures targeting F-gases, two scenarios need to be developed by following the same method that is applied to estimate emissions in the national inventory (e.g. for the case of Greece a Tier 2a from the 2006 IPCC guidelines is applied): a baseline / WOM scenario that does not include the effect of the implementation of the ‘F-gas Regulation’; and a WEM scenario that reflects the provisions of the legislative act. Given that some of the provisions of the legislative act are difficult and more uncertain to quantify (e.g. training and qualification), the WEM scenario should reflect at least the provisions that are associated to the restrictions and ban on use of specific gases (Annex III of the F-gas Regulation).

The activity data of refrigeration and air-conditioning equipment could be extrapolated based on the trends of historical data and expert judgement. The mitigation effect would be the difference between the two scenarios WOM-WM.

2.2.7 Waste sector

Policies and measures relating to the solid waste disposal, biological treatment of waste, waste incineration and open burning of waste, as well as wastewater treatment and discharge, are climate relevant. Methane represents the major greenhouse gas from waste sector, which mainly arises from the treatment and disposal of solid waste [21]. The analysis in this section focuses on the solid waste disposal on land, since this emission source category prevails in the waste sector.

In the solid waste disposal category, biodegradable waste is of interest in terms of GHG emissions, since this is the waste fraction delivering most CH4 emissions during anaerobic decomposition. The necessity to reduce the quantities of biodegradable waste going to landfills is acknowledged by the Directive 1999/31/EC. Within the framework of the national strategy for the reduction of biodegradable waste, Greece has the target to limit the biodegradable waste going to landfills in 2020 to 35% of the biodegradable waste produced in 1997. In addition, pursuant to the Directive (EU) 2018/850 for the amendment of Directive 1999/31/EC on the landfill of waste, the target to limit the generated municipal solid waste that is disposed to landfills up to 10% by 2035 was introduced. Further, it is required that landfills receiving biodegradable municipal waste are equipped with landfill gas recovery systems [21].

For the estimation of the mitigation effects in the solid waste disposal category, two scenarios were developed by applying the same model used in

GHG inventory: a baseline/WOM scenario that follows historical observed trends; and a WEM scenario that reflects the implementation of the National Waste Management Plan on the production of waste streams, waste composition, recycling, recovery and disposal. The mitigation effect relevant to the recovery of biogas is estimated based on current and projected share of population that is served by managed waste disposal sites, which are equipped with biogas recovery systems.

2.2.8 Agriculture sector

Agricultural activities can result in methane emissions from livestock digestion processes and storage of animal manure. In addition, the use of organic and mineral nitrogen fertilizers can lead to nitrous oxide emissions. The agriculture sector in Greece and other Member States has the specialty that is mainly driven by one policy, the Common Agricultural Policy (CAP), which determines a common way for all Member States of the European Union. The present day CAP contains both a climate action objective, a number of measures (both compulsory and voluntary for farmers and Member States) which are intended to secure climate benefits (Pillar I – direct payments to farmers), and a requirement for a minimum proportion of funding to be spent on environment and climate measures (Pillar II – rural development policy). These arrangements have developed over time. In Greece, the implementation of the current Common Agricultural Policy (CAP) regulations started in 2015 (with 2014 being a transitional year) [21].

The direct payment to farmers (Pillar I) contains a 'greening' component, which serves as an additional support to offset the cost of providing environmental public goods that are not remunerated by the market. In Greece, in order to receive the greening part of the direct payments, the following agricultural practices with direct climate impact should be followed: crop diversification, maintaining existing permanent grassland, and maintaining an 'ecological focus area' of at least 5% of the arable area of the holding on farms with more than 15 hectares of arable land (e.g. fallow land; afforested areas and landscape elements; Nitrogen-fixing crops). In addition, cross-compliance requirements apply to all components of the direct payments, which have climate-related aspects, e.g. measures for the proper use of synthetic and organic fertilizers, measures for protection of soil carbon and retention of landscape features. Further, as an indirect effect, the disengagement of subsidies from the agricultural production has led to the reduction of agricultural production and livestock population, which result in the reduction of emissions from the agriculture sector [21].

The rural development policy (Pillar II) includes measures that reduce CH_4 and N_2O emissions from the agriculture sector, namely organic farming, measures to reduce or rationalize fertilizer application, and measures in livestock management. It also includes measures targeting adaptation to climate change (e.g. measures related to water savings), energy efficiency and investments in RES, and carbon conservation and sequestration measures in agriculture and forestry [21].

Due to lack of data about the effect of CAP in the mitigation of GHG emissions, the estimation of the mitigation effect in agriculture sector is based on expert judgement and conclusions extracted by the comparison of gross domestic product (GDP) and gross value added of agriculture (GVA) evolution and the decreasing trend of historical GHG emissions and associated activity data. Two scenarios were developed based on the emission model that is used in the national GHG inventory: a baseline / WOM scenario reflecting the assumption that animal population and crop production follows the GDP evolution, i.e. increase by 3.5% per year for the period 2020–2030; and a WEM scenario reflecting the assumption that animal population and crop production follow the evolution trend of GDP, i.e. an increasing trend, but with reduced increasing rate, as it was calculated based on historical data for the years where already a part of CAP policies has been implemented. The reduced increasing rate compared to WOM scenario is attributed to the effect of CAP (pillar I and II) and the disengagement of subsidies from the agricultural production.

3 Case Study: Greece

By applying the methodological framework, which was presented in previous sections, the total realistic quantifiable GHG emissions reduction potential from the mitigation actions of Greece was estimated for years 2020, 2025 and 2030. In addition, an ex-post analysis of the mitigation effect was performed for year 2015. The results of the analysis are presented in Table 1.

The total effect of mitigation actions in 2015 was calculated to be 25.8 Mt CO_2eq, which is 25% of year 1990, which is the base year of the Climate Convention (UNFCCC). Further, the total effect of the mitigation actions, including implemented, adopted and planned policies and measures that are included in the National Energy and Climate Plan of Greece [22] are estimated to be 33.1 Mt CO_2eq for 2020, 48.4 Mt CO_2eq for year 2025 and 57.3 MtCO_2eq for year 2030, which are 32%, 47% and 55% of the base year emissions of Greece, respectively.

Table 1 Ex-post and ex-ante analysis of the effect of mitigation actions in Greece

No	Name of Mitigation Action	Sectors Affected	GHGs Affected	Objective and/or Activity Affected	Ex-post Mitigation Effect (ktCO2eq)	Ex-ante Mitigation effect (ktCO2 eq)		
					Year 2015	Year 2020	Year 2025	Year 2030
1	Improvements in the conventional power generation system	Energy	CO2	Efficiency improvement in the energy and transformation sector; Switch to less carbon-intensive fuels	7400	15,000	13,300	10,400
2	Promotion of natural gas in residential sector	Energy	CO2	Efficiency improvements of buildings	260	320	390	475
3	Promotion of natural gas in tertiary sector	Energy	CO2	Efficiency improvement in services/ tertiary sector	120	140	170	210
4	Promotion of natural gas in industry	Energy	CO2	Efficiency improvement in industrial end-use sectors	638	814	1596	2246
5	Promotion of natural gas in transportation	Transport	CO2	Low carbon fuels	11	18	22	44

(*Continued*)

Table 1 Continued

No	Name of Mitigation Action	Sectors Affected	GHGs Affected	Objective and/or Activity Affected	Ex-post Mitigation Effect (ktCO2eq)	Ex-ante Mitigation effect (ktCO2 eq)		
					Year 2015	Year 2020	Year 2025	Year 2030
6	Promotion of RES for electricity generation	Energy	CO2	Increase in renewable energy	14,700	11,000	22,823	30,792
7	Biofuel use in transportation	Transport	CO2	Low carbon fuels	490	650	780	1129
8	Implementation of energy efficiency measures in Industry (National Energy Efficiency Action Plan)	Energy, Industry/ industrial processes	CO2	Efficiency improvement in industrial end-use sectors	–	200	200	200
9	Implementation of energy efficiency measures in Residential and Tertiary Sector (National Energy Efficiency Action Plan)	Energy	CO2	Efficiency improvements of buildings; Efficiency improvement in services/ tertiary sector; Efficiency improvement of appliances	180	2,200	4,570	5,390
10	Road transport measures	Transport	CO2, CH4, N2O	Efficiency improvements of vehicles; Modal shift to public transport or non-motorized transport; Low carbon fuels/electric cars	300	560	646	840

11	Mitigation actions in waste sector	Waste management /waste	CH4	Reduced landfilling; Enhanced recycling; Improved landfill management; Enhanced CH4 collection and use	1180	1000	1500	2000
12	Reduction of emissions of fluorinated gases	Industry/industrial processes	HFCs, PFCs	Reduction of emissions of fluorinated gases; Replacement of fluorinated gases by other substances	–	460	1400	2300
13	Mitigation actions in agriculture sector	Agriculture	CH4, N2O	Improved livestock management; Improved animal waste management systems; Sustainable development of agricultural activities and rural areas, with a focus on climate change mitigation and adaptation objectives; Reduction of fertilizer/manure use on cropland	560	715	1000	1300

4 Conclusions

The quantification of the effect of policies and measures to mitigate climate change is a 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. It is also a reporting requirement according to the current reporting framework of the UNFCCC and the forthcoming Enhanced Transparency Framework of the Paris Agreement. In addition, it is a reporting requirement for the climate-related reporting of EU Member States to European Commission. However, according to the assessment of European Environmental Agency [16, 17], the reporting of both ex-post and ex-ante emission savings by EU Member States is incomplete at a significant extent.

The proposed methodological framework, which was presented in this paper, is currently applied by Greece for the assessment of the effect of mitigation actions. The methodology is based on comprehensive and transparent models and formulas that could be easily tracked and reproduced. It is suitable for both ex-post and ex-ante evaluation and any possible interferences between policies and measures are taken into account in order to avoid double counting. Since the activity data and information required by the proposed framework are mainly based on the available official information that is reported by Member States through the various reporting channels to European Commission and UN bodies, the framework could be easily applied by EU Member States, but also by other countries, to enhance the accuracy and consistency of monitoring and reporting of the impact of mitigation actions.

By applying the methodological framework proposed, it was possible to estimate the total effect of mitigation policies of Greece for year 2015 (ex-post analysis), but also for years 2020, 2025 and 2030 (ex-ante analysis), by using available official information and reporting of Greece to EU and UN. The total effect of implemented mitigation actions in 2015 was calculated to be 25% of year 1990, which is the base year of the Climate Convention (UNFCCC), while the total effect of the mitigation actions, including implemented, adopted and planned policies and measures that are included in the National Energy and Climate Plan of Greece [22] are estimated to be 32%, 47% and 55% of the base year emissions of Greece for years 2020, 2025 and 2030, respectively.

References

[1] Pachauri, R K and Meyer L A (Eds.). Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC, Geneva, Switzerland, 2014.

[2] World Meteorological Organization. The State of the Global Climate 2020, https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate (2020, accessed 12 May 2021).

[3] UNFCCC. Adoption of the Paris agreement. Report FCCC/CP/2015/L.9/Rev.1, https://unfccc.int/sites/default/files/english_paris_agreement.pdf (2015, accessed 12 May 2021).

[4] Blau J. The Long, Long Road to Paris. In: The Paris Agreement. Palgrave Macmillan, Cham, 2017, pp. 23–31.

[5] Sebos I et al. Mitigation and Adaptation Policies Related to Climate Change in Greece. In: Grammelis P (eds) Energy, Transportation and Global Warming. Green Energy and Technology. Springer, 2016, pp. 35–49.

[6] Kallinikos L et al. Greenhouse Gas Emissions Trends from Waste in Greece. In: Grammelis P (eds) Energy, Transportation and Global Warming. Green Energy and Technology. Springer, 2016, pp. 131–144.

[7] Müllerová M, Krtková E and Rošková Z. F-Gases: Trends, Applications and Newly Applied Gases in the Czech Republic. *Atmosphere* 2020; 11: 455–464.

[8] Niu J et al. The long-run relationships between energy efficiency and environmental performance: Global evidence. *Energy Environ.* 2017; 28(7): 706–724.

[9] Li W, Yang M and Sandu S. Electric vehicles in China: A review of current policies. *Energy Environ.* 2018; 29(8): 1512–1524.

[10] World Resources Institute. Questionnaire on GHG Mitigation Action/Policy Accounting & Mitigation Goals Accounting – Summary of Results from Online Questionnaire, https://www.transparency-partnership.net/sites/default/files/wri_questionnaire_results_-_october_2011_0.pdf, (2011, accessed 12 May 2021).

[11] UNFCCC. Decision 4/CP.5: Guidelines for the preparation of national communications by Annex I Parties, Part II: UNFCCC reporting guidelines on national communications, https://unfccc.int/resource/docs/cop5/06a01.pdf#page=8 (1999, accessed 12 May 2021).

[12] UNFCCC. Decision 2/CP.17 (Annex I): UNFCCC biennial reporting guidelines for developed country Parties, https://unfccc.int/resource/docs/2011/cop17/eng/09a01.pdf#page=4 (2011, accessed 12 May 2021).
[13] UNFCCC. Decision 2/CP.17 (Annex III): UNFCCC biennial update reporting guidelines for Parties not included in Annex I to the Convention, https://unfccc.int/resource/docs/2011/cop17/eng/09a01.pdf#page=39 (2011, accessed 12 May 2021).
[14] UNFCCC. Decision 18/CMA.1 – Modalities, procedures and guidelines for the transparency framework for action and support referred to in Article 13 of the Paris Agreement, https://unfccc.int/sites/default/files/resource/CMA2018_03a02E.pdf (2018, accessed 12 May 2021).
[15] Regulation (EU) No 525/2013 of the European Parliament and of the Council of 21 May 2013 on a mechanism for monitoring and reporting greenhouse gas emissions and for reporting other information at national and Union level relevant to climate change and repealing Decision No 280/2004/EC.
[16] European Environmental Agency, EEA. National policies and measures on climate change mitigation in Europe in 2017 – Technical overview of the information reported by Member States under the European Union's climate Monitoring Mechanism Regulation. EEA Report No 9/2018, https://www.eea.europa.eu/publications/national-policies-and-measures-on-climate-change-mitigation (2018, accessed 12 May 2021).
[17] European Topic Centre on Climate change mitigation and energy. Overview of reported national policies and measures on climate change mitigation in Europe in 2019. Eionet Report – ETC/CME 5/2019, https://www.eionet.europa.eu/etcs/etc-cme/products/etc-cme-reports/etc-cme-report-5-2019-overview-of-reported-national-policies-and-measures-on-climate-change-mitigation-in-europe-in-2019 (2019, accessed 12 May 2021).
[18] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.
[19] Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast).
[20] Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and

(EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council.

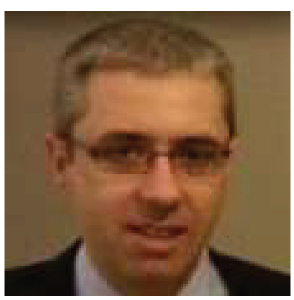
[21] Greek Ministry of Energy and Environment. 4th Biennial Report under the United Nations Framework Convention on Climate Change of Greece, https://unfccc.int/BRs (2020, accessed 12 May 2021).

[22] National Energy and Climate Plan of Greece, https://ec.europa.eu/energy/sites/ener/files/documents/el_final_necp_main_en.pdf (2019, accessed 12 May 2021).

Biographies

Ioannis Sebos (or Sempos) works as a Teaching and Research Associate at National Technical University (NTUA). He also serves as the scientific responsible and coordinator of the Greenhouse Gas Inventory System of Greece. He is a Lead Reviewer of UNFCCC and EEA/EC. He is also a lecturer at the Master Program "Applied Policies and Techniques for the Protection of Environment" of the University of West Attica and adjunct professor at Master Program "Environmental Design" of the Hellenic Open University. Furthermore, he has participated in many technical projects dealing with: inventories of gaseous emissions, solid and liquid waste, renewable energy, climate change mitigation and adaptation strategies and policies, industrial risk assessment and land use planning, etc. He has more than 5 years working experience in various industries, including cement industry, construction industry, third party logistics, etc. He is also an Assessor for Certification Bodies of Quality Management, Safety and Environmental Systems of the Hellenic Association System (ESYD). He is the author of more than 30 articles in peer-reviewed journals and/or presentations in scientific conferences.

Athena G. Progiou has studied Physics and possesses a D.E.A. in Chemistry of the Atmospheric Pollution and Environmental Physics and a PhD in the field of environmental engineering. She has an important experience through her participation in more than 100 environmental national and European projects with emphasis on atmospheric pollution and climate change. She was evaluator for the 7th Framework Program and for the Horizon 2020 Program proposals, monitor for Horizon projects as well as reviewer in scientific journals in the fields of her expertise. She has 50 publications in peer reviewed journals and conferences. Currently, she is the coordinator of the EU project "Integrated approach for exposure and health effects monitoring of engineered nanomaterials in workplaces and urban areas".



Leonidas Kallinikos is a key member of the NTUA Team that runs the National Greenhouse Gas Inventory System. He has thirteen years of professional experience in scientific projects related to energy, environment and emissions from agriculture and waste sectors. Moreover, he has participated in several projects as a process engineer carrying out activities related to detailed design works, front end design, debottlenecking, process and feasibility studies for several refineries and other big chemical factories. He has extensive technical experience in data management, emission estimation and development of mathematical simulation models using various programming languages and relevant software. He has 11 publications in peer-reviewed international journals, while his Phd thesis was awarded as the best experimental doctoral thesis of the School of Chemical Engineering – NTUA for 2010 (“Stamos Stournas” Award).