Strategies for reducing the carbon footprint and tackling energy poverty in Greek households

February 2024

Citation:

Mirasgedis Sebastian, **Sarafidis** Yiannis, **Lalas** Dimitri & **Mantzaris** Nikos (2024), *Strategies for reducing the carbon footprint and tackling energy poverty in Greek households*. Facets & The Green Tank.

Format Design:

Design Nature

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Summary

The recent major upheavals and volatility in the energy prices have made it necessary for governments in all European Union Member States to provide extraordinary subsidy support to households to help them cope with the excessive cost of covering their energy needs. In addition, the EU is finalizing the legislative components of its European Green Deal and quantifying its renewables, energy conservation and GHG emission targets for 2030 to be embedded in the Member States revised NECPs which have to be submitted in final form by June 2024. Motivated by the above, this study focuses on the energy consumption of Greek households and especially on the energy used for space heating/cooling and the use of appliances as well as for passenger transport in the very-near term (the next 2-3 years) and the near term (2025 to 2030), exploring ways to meet their energy needs under conditions of particularly volatile energy prices and simultaneously reduce their carbon footprint as well as examining how available resources including national subsidies, NextGenerationEU and Cohesion Funds be better allocated. Specifically, it explores the optimal mix of interventions that will lead to reduction by the Greek households of their energy use and hence costs and GHG emission reduction without significant deterioration of their living conditions in a cost-effective manner, aiming to address, for the residential housing sector,

- to what extent the promoted electrification of thermal uses (mainly with heat pumps) and the penetration of more efficient devices should be coordinated and combined with the energy upgrade of the existing building stock
- where, for a given expenditure, is the right balance between shallow renovation of a lot of buildings vs deep renovation of fewer ones
- the role of energy sufficiency and behavioral change measures
- whether RES (mainly PV) should be included in building renovation or rely on the greening of the grid electricity

and for the transport sector

- to what extent the electrification of vehicles fleet should be accompanied with measures to switch to public transport, improve driving behavior or reducing transport activity
- to what extent energy sufficiency measures can contribute to reducing energy consumption and the associated GHG emissions

To address these questions, a number of interventions for both sectors that affect household energy use and GHG emission have been considered to be deployed in ten scenarios, eight for the building sector and two for the transport sector (shown in Table SE1). The measures considered in these scenarios in the housing sector covered efficiency (deep and shallow renovation, heat pumps, installation of insulation films on single glazing, replacing remaining inefficient light bulbs), sufficiency (adjusting heat and cooling set points, reduction of temperature by 2°C at night, switching off standby and unnecessary devices when absent, smarter settings for household

appliances) as well as use of RES systems (use of PV and solar thermal systems). In the transport sector, the efficiency measures considered were the enhanced use of BEVs, and the sufficiency ones including reduction of speed limits, soft mobility, teleworking, enhanced use of public transport and carpooling.

Table ES1: Scenarios considered	
Residential Sector (8 scenarios)	
S0	Assumes a strong penetration of easy to implement efficient and clean technologies, including heat pumps, solar systems for hot water, efficient lighting, and insulating films.
S1	Based on S0 with the additional incorporation of the sufficiency interventions of Table 4.
S2	Focus on shallow renovations of approximately 100,000 dwellings per year and simultaneously comprises all the interventions included in S0 and S1. In this context, the new heat pumps installed are resized due to the reduced energy demand attributed to the energy renovation of the dwellings.
S3	Like S2 but including deep instead of shallow renovations in a slightly lesser number of dwellings (80,000 homes on an annual basis until 2030).
Sx-PV	In S0-PV – S3-PV (4 scenarios) the installation of 2 GW of roof-top photovoltaics is added to the packages of interventions included in each of the scenarios S0 – S3.
Transport Sector (2 scenarios)	
T1	Only considers the electrification of the vehicle fleet, as defined in Table 4.
T2	Assumes that both the electrification of the vehicles fleet and the whole set of sufficiency measures included in Table 1 are implemented. Compared to T1 scenario, the number of electric vehicles introduced is the same but with lower mileage per vehicle.

The efficacy of the measures as combined in the ten scenarios has been based on the resulting annual reduction of GHG emissions and the associated annualized and discounted cost. The metric used in the annualized abatement cost of GHG reduction (in EUR/tCO2eq) computed by considering the expenditure and the emissions over the lifetime of the measure above and beyond emissions of measures already in effect in 2022. The cost takes into consideration both scope 1 and scope 2 emissions but also the investment and energy cost to households. The effect of the upcoming inclusion of the housing sector in the EU-ETS2 has also been considered.

In view of the recent volatility of the energy prices, a sensitivity analysis with low, moderate, and high future energy prices has also been carried. In addition, the sensitivity analysis also included different discount rates to take into account the long lifetimes of improvements.

The results in the residential housing sector show that the scenarios installing PV on top of shallow or deep renovations, heat pumps and sufficiency measures (i.e., S2-PV and S3-PV) lead to net profits for the period 2023-2030 as indicated by the negative values of annualized expenditures, which include not only the investment costs but also the economic benefits for the households. These values range from -€6 Mn up to -€561 Mn per year in 2030, depending on the values of the parameters examined in the sensitivity analysis we conducted (energy prices, discount rates). High energy prices make the S3 scenario without PV as well as the S1-PV (i.e. the promotion of heat pumps and photovoltaics without energy renovations) also financially viable.

Since the mix of measures we propose is different than that of the NECP, differences in the total investment costs are also expected. Although it is difficult to make precise comparisons due to the lack of knowledge of the specific assumptions employed in the NECP, we note that, according to the latter, the total expenditures dedicated to the residential sector (renovations and energy appliances) for the period 2023-2030 is 29.2Bn (€6.3 Bn for renovations and €22.9 Bn for appliances). On the other hand, the total investment costs for our scenarios S0, S1, S2 and S3 for the same period are € 8.7 Bn, € 8.8 Bn, € 19.1 Bn and € 25 Bn, respectively. Moreover, the total investment costs for the two scenarios which emerged from this analysis as the most economically efficient (S2-PV and S3-PV), range from €22.7-28.6 Bn, lower or at the same order of magnitude with that of the draft NECP. However, almost 50% in S2-PV or even more in S3-PV of the investments in these scenarios concern renovations of old dwellings. The annualized expenditures that were calculated for these scenarios, have been found to be negative under a wide range of parameter values (figures 12-15). In addition, both scenarios (S2-PV and S3-PV) which emphasize building renovation in conjunction with PV, have negative costs per tonne of CO2 emissions reductions they achieve for every year during the study period (Table 7), thus both scenarios were shown to be simultaneously beneficial for the climate and the national economy.

In the transport sector, the T1 scenario which comprises enhanced electrification on the same extent as the current NECP will lead to emission reduction (30% by 2030 wrt 2022, i.e., 630ktCO_2eq) at a high investment cost (ca 22.9Billion EUR) as it assumes that by 2030 18.5% of the vehicle fleet to be BEV. Of interest here is to examine the additional reductions to be obtained with the sufficiency measures, not emphasized by the NECP, such as the reduction of the maximum speed limit, soft mobility, carpooling and tele-working, included in the T2 scenario. The analysis shows that at very low extra cost these measures lead to an additional 812-822 ktCO_2/year reduction in emissions and an additional savings in household energy costs between 514 and 710 mn EUR depending on the actual level of the fuel prices, compared to only emphasizing electromobility as is the case with the NECP.

The full results of the analysis provide the basis for a number of policy recommendations to policy makers, namely:

1. Institute an obligatory replacement of fossil fuel-based heating systems (oil and gas) with heat pumps when implementing renovation of the existing building stock, which has the added advantage of resizing the heat pumps to meet the reduced energy needs of the renovated structures.
2. Implement measures to encourage changes in consumer choices towards sufficiency while ensuring adequate living comfort and thus avoiding a rebound effect.
3. Choose deep renovation in designing renovation support measures, but shallow is also acceptable as is a combination of the two.
4. Support the increase in the installation rate of small PV systems for self-consumption purposes, especially in conjunction with renovation, possibly in combination with battery storage systems. Energy communities can also play an

important role in facilitating the use of PV systems to cover the households' electricity needs.

5. Redirect funds aimed at supporting replacement of household appliances to supporting heat pump utilization, as well as to increasing the installation rates for solar water heaters and PV systems.
6. Initiate communication campaigns highlighting the favorable economics of investing in renovations, heat pumps and PV systems.
7. Implement in the transport sector, sufficiency measures (speed limit reduction, soft mobility, carpooling, teleworking) which result in a substantial GHG emission reduction that exceeds in total that of the BEV penetration till 2030.

Even though all of the policies and measures (PaMs) analyzed are already in operation in one form or another or have been under consideration in Greece and in other countries, this analysis has identified combinations of policies and measures, especially for sufficiency, that are effective in reducing emissions at low or no cost in the residential housing and passenger transport sectors. It is hoped that its findings will be taken into account in the compilation of the final form of the Greek revised NECP. It is also hoped that in view of the methodology followed that enables the examination of alternative scopes of such PaMs in a transparent but robust bottoms-up approach, which is easily reproducible, and has minimal computation resources needs, it can be of help to other countries or regions and especially to civil society organizations that are interested in social aspects of energy impacts as well as to other political organizations in proposing enhancement to or alternative policies to those put forth by the government so far.

1. Introduction

1.1 Setting the stage - aims of the study

Following the disruptions that have been caused by the COVID pandemic and the problematic recovery from the measures put in place by all EU MS to address their adverse impact on their economies, an energy crisis ensued in the second half of 2021 originally due to a mismatch of supply and demand in oil and gas and subsequently exacerbated by the invasion of Ukraine by Russia in February 2022 and the weaponizing of fossil fuel energy carriers. Greece has also been hit hard by the energy price crisis, which forced the Greek Government to take measures in an attempt to contain it. Since the beginning of the crisis in fall 2021 and until the end of 2022, EUR 10.7 billion has been spent to relieve the economic burden of households and businesses arising from the soaring electricity and fuel costs. All of these measures however, subsidized, directly or indirectly, fossil fuel consumption and consequently, will not have a long-lasting effect in reducing the carbon footprint and the energy bills. As the high fuel price regime continues to ensue and the available funds for direct household assistance to ameliorate their energy costs become depleted, turning to such policies and measures is of paramount importance in the short term (next 2-3 years). It is also equally significant for the medium and longer term as Greece has already set ambitious climate targets for 2030, 2040 and 2050 in its recently voted (June 2022) first national Climate Law, the compliance with which is the main objective of the currently on-going revision of Greece's National Energy and Climate Plan (NECP).

Motivated by the above, this study focuses on the energy consumption of Greek households and especially on the energy used for space heating/cooling and the use of appliances as well as for passenger transport. In the next 2-3 years Greek households will face a double challenge:

(i) to meet their energy needs under conditions of particularly volatile fossil gas and electricity prices, and
(ii) to reduce their carbon footprint.

As huge amounts of money are already being spent by the Greek government on reducing energy bills in Greek households, the study examines whether these resources can be allocated so that the problem of lowering energy costs and reducing emissions can be tackled in an integrated and permanent way. Specifically, it explores the optimal mix of interventions that will lead to the achievement of these two goals as well as the appropriate package of policies that should be implemented immediately in order to achieve this transformation. In other words, the study aims to explore, given an amount of funds and a fixed time frame, how and how much can Greek households reduce their energy use without deterioration in the quality of their living conditions.

1.2 The Greek residential sector

The energy performance of residential buildings is of paramount importance for decarbonizing the economies and mitigating climate change as well as for ensuring adequate indoor conditions with affordable prices of fuel and energy services. Recognizing the critical role of the buildings sector, the European Commission and by extension the Greek State have tried to implement during the last two decades various policies and measures with the aim of upgrading its energy performance, reducing energy consumption, and, thus, reducing its carbon footprint.

As shown in **Figure 1**, the total energy consumption in the Greek residential sector decreased from 4.6 Mtoe in 2000 to 4.3 Mtoe in 2021 (-9.4%). The trend, however, was not uniform. For about 12 years (2000 -2011), energy consumption is seen to increase albeit with fluctuations. Its de-escalation begun in 2012. It coincided with the financial crisis that hit the Greek economy in the 2010s, and seems to have played an important role in changing energy behaviors of households. During the first 2-3 years after the onset of the financial crisis, the use of central heating systems with diesel oil was gradually abandoned by roughly one in two households and the share of petroleum products in the total energy consumption of the residential sector decreased from 53% in 2000 to ca 25% by 2013 and to 27% in 2021, mainly because of increased oil prices and reductions in households' income. In the same period, the role of fossil gas and electricity increased, with the former covering 12% of total energy needs in the residential sector in 2021 from almost zero in 2000, and the latter covering 36% of the energy needs in 2021 from 27% in 2000. The share of RES increased from 19% in 2000 to 25% in 2021, with biomass used for space heating and solar energy for hot water being the renewables (henceforth RES) with the highest contributions in the sectoral energy mix. In other words, the policies implemented during the last twenty years in the residential sector, combined with the impact of the economic crisis of the 2010s, seem to have had only a small effect on the total energy consumption of the sector, but a much more significant impact on the mix of energy resources used to meet the energy needs of the residential sector.

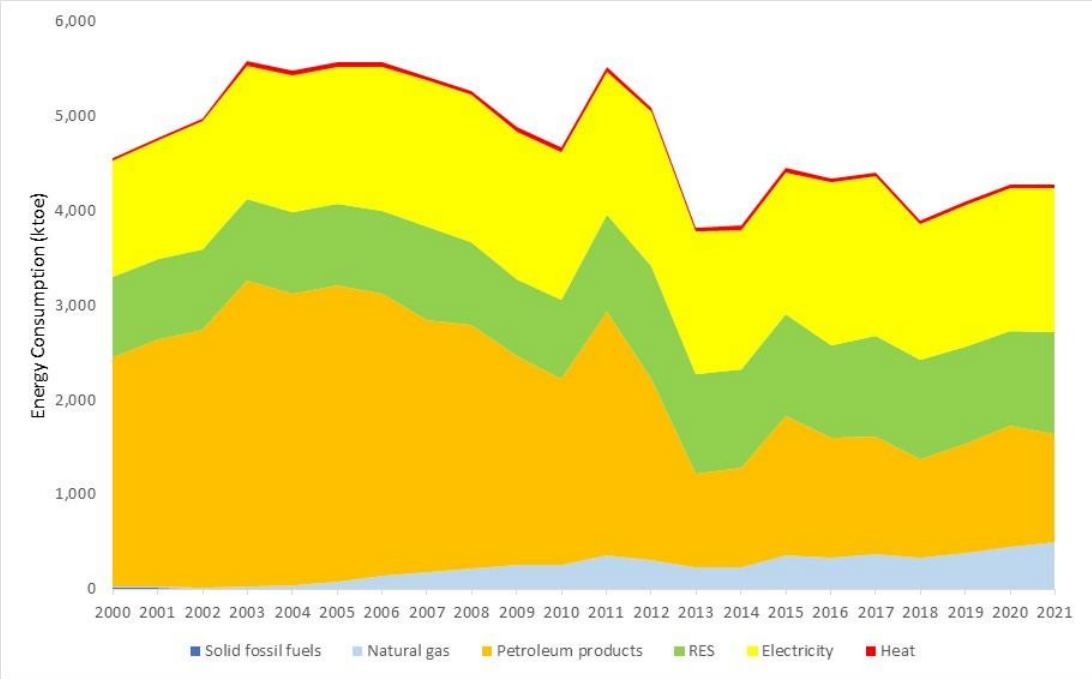


***Figure 1**: Final energy consumption in the Greek residential sector the period 2000-2021 (ktoe). Source: Eurostat, [nrg_bal_s].*

Figure 2, shows the evolution of direct (i.e., from the use of fuels) and indirect (i.e., from the use of electricity) CO_2 emissions of the sector. The reductions achieved in the period 2012-2021 were impressively large (more than 53%) compared to the period 2000-2012, during which a 4% increase was recorded. The diversification of the energy mix used both directly in buildings and in power generation were the main factors that contributed to this development.

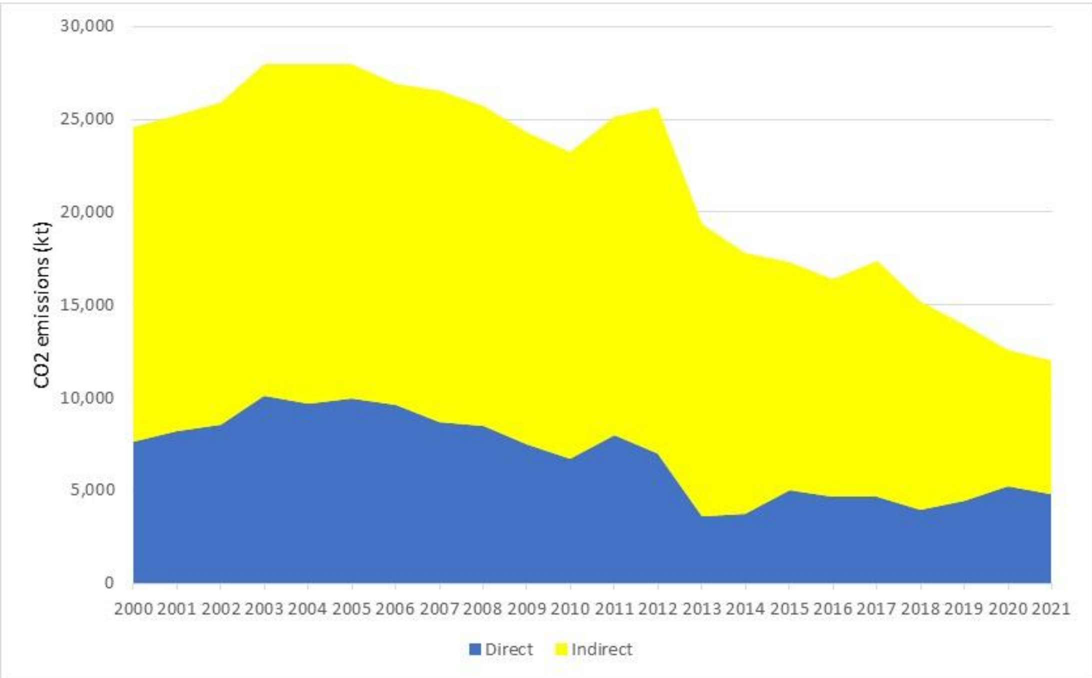


Figure 2: *Direct (S1) and indirect (S2) CO_2 emissions from the Greek residential sector the period 2000-2021 (kt). Source: Eurostat [env_air_gge] and own calculations.*

A more detailed decomposition of the parameters that contributed to the reduction of the carbon footprint of the Greek residential sector in the period 2000-2021 is shown in **Figure 3**[1]. The total reduction in emissions amounts to 51% or 12.6 Mt CO_2. Of those, 11.5 Mt CO_2 (91% of the total reduction) can be attributed to the use of cleaner fuels on site in homes and reductions in the carbon footprint of the power generation sector. The implementation of energy savings measures in the sector (such as the energy upgrading of the building stock, the use of energy efficient appliances, etc.) would have theoretically yielded another 4.3 Mt CO_2 of emission reductions, however almost 96% of them (i.e., 4.2 Mt CO_2) were "lost" due to changes in households' behavior (i.e., people living in more and bigger houses, using more appliances, or running the heating longer in order to achieve better thermal comfort conditions). Finally, 7.5% of the emissions reduction in the sector during the period 2000-2021 is attributed to more favorable climate conditions.

Therefore, the significant improvement of the carbon footprint of the Greek residential sector in the period 2000-2021 is, to a large extent, related to the diversification of the energy mix, and mainly to the substitution of heating oil with fossil gas and electricity, combined with the fact that in the same period the carbon footprint of electricity generation in Greece was significantly reduced due to policies promoting RES and fossil gas in conjunction with the drastic reduction in the use of lignite accompanied by the decommissioning of a large part of the lignite plant capacity. The effect of the economic crisis on the diversification of the energy mix in the sector was profound. Energy saving interventions promoted during the same period yielded much lower energy savings and improvements in the sector's carbon footprint than expected. The latter is probably related to the high levels of energy poverty in Greece, as a significant percentage of the households are unable to adequately heat and cool their homes, which is probably due to a strong rebound effect. In other words, the applied energy savings measures helped households in receiving better energy services, rather than reducing their energy consumption.

[1] A decomposition analysis based on the LMDI method, first introduced by Ang and Liu (2001) has been implemented. As explanatory variables we have used the number and size of dwellings, weather conditions based on heating degree days, the technical potential of energy saving measures implemented, behavioral changes and the carbon intensity of energy sources used. The data were derived from Eurostat, Odyssee database, the Hellenic Statistics Authority, the 4th National Action Plan for Energy Efficiency, and the Statistical Report on EPC of the Greek buildings (2022).

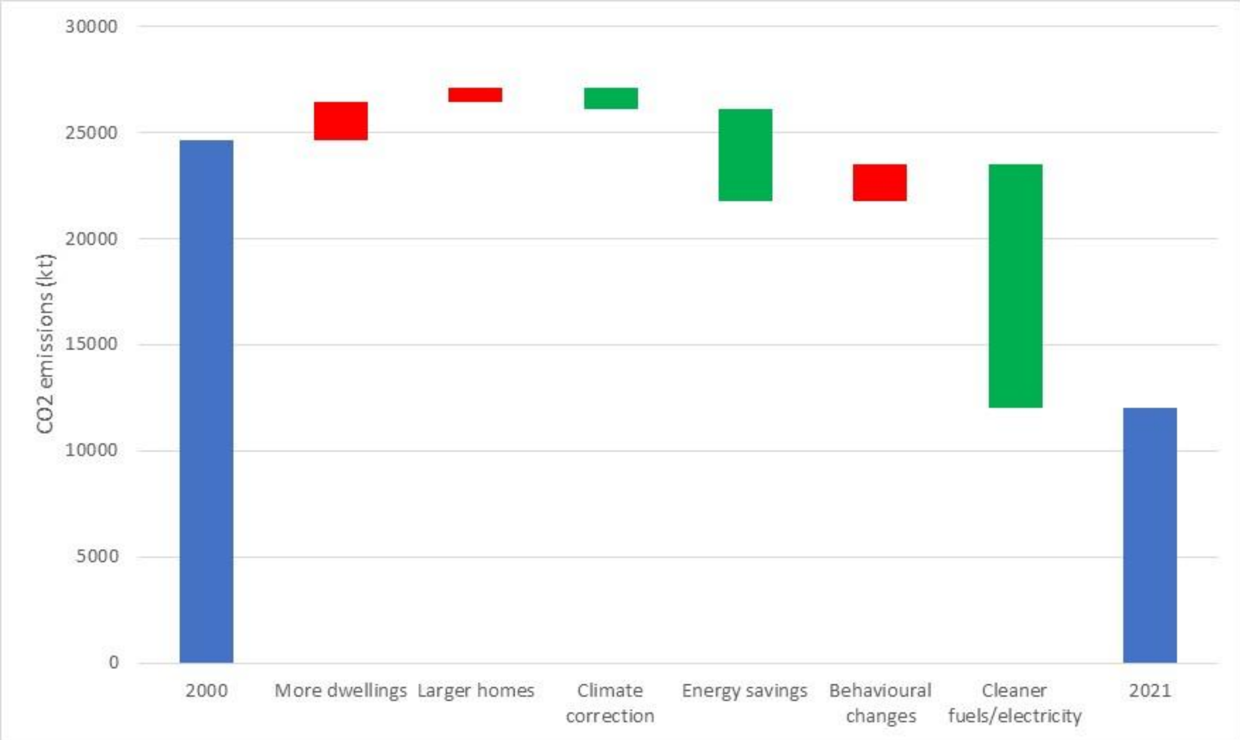


***Figure 3**: Decomposition of the evolution of the direct and indirect CO_2 emissions from the residential sector in the period 2000-2021.*

The evolution of energy poverty in Greece during the last 20 years (2003-2022) is presented in **Figure 4** based on three subjective indicators drawn from the EU-SILC survey conducted annually in all Member States.

According to indicator S1 (inability to keep house adequately warm), fuel poverty in Greece displayed a considerable deterioration in the period 2010-2014 mainly due to the economic recession, while an improvement was observed in the following years and especially since 2017. In 2014, approximately one out of three households and more than half of the poor households were unable to adequately heat their residence. However, the number of households with insufficient heating in 2019 was only slightly higher than it was in 2010 (at the beginning of the financial crisis), while the percentage of poor households with inability to adequately heat their residences was lower than the respective figure in 2010 (but maintained at the level of 35%). A slight deterioration of the indicator is observed again in the period 2021-2022, most likely due to the increased energy prices.

The evolution of indicator S2 (arrears on utility bills) was similar (but with a 1-2-year lag) as the percentage of households with difficulties in paying energy bills increased from 2010 and until 2016. That year the energy poverty affected 42.2% of all households and over 65% of poor households in Greece. Despite the slight improvement in the subsequent years, indicator S2 does not follow the spectacular de-escalation of indicator S1, mainly due to high energy prices and the low increase of households' income. Moreover, the rate of energy poverty alleviation is worse in the poor households. A significant deterioration of this index was observed in 2022 apparently, due to the large increases in the prices of energy products.

Finally, the analysis of indicator S3 (living in a dwelling with leaky roof, damp walls, floors or foundation or rot in window frames or floor) displays a continuous improvement throughout the examined period. The construction of new buildings and particularly the energy-related renovations of the existing ones improve the energy performance of the existing building stock, which plays a crucial role in alleviating fuel poverty in the long run.

The analysis of the three subjective indicators in question shows that energy poor people are in all income percentiles, however the phenomenon of energy poverty is significantly more pronounced among poor households. The fluctuation of the indicators S1 and S2 during the period 2010-2021 shows that to a large extent the very high rates of energy poverty (above 25%) recorded in Greece for several years of the period under examination, are due to the economic crisis, the reduction of households' income (from 2010 to ca 2016), and the rising energy prices which was not matched by an adequate increase in income. On the other hand, 15% of the country's households live in houses with significant operational problems. In their case, the problem of energy poverty is likely to have more structural features.

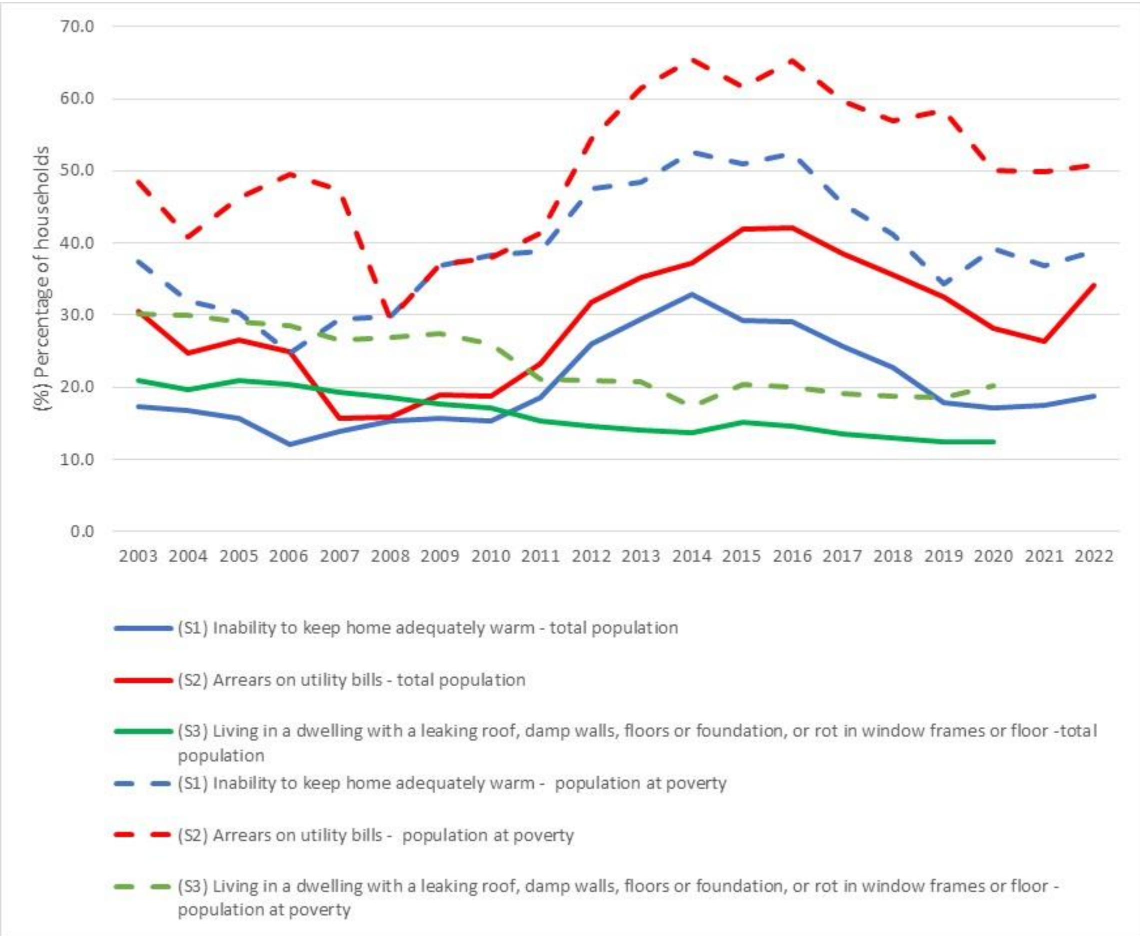


***Figure 4**: Evolution of energy poverty indicators in Greece. Source Eurostat, EU-SILC Survey.*

1.3 Passengers transport in Greece

The transport sector in Greece (excluding international aviation and bunkers) accounted for about 37% of final energy consumption in 2021, according to Eurostat data on national energy balances. In terms of contribution to the total final consumption, there were no significant changes compared to 2000, as its share in 2000 was 36%. Total energy consumption in the sector (**Figure 5**) decreased from 6.5 Mtoe in 2000 to ca 5.4-6 Mtoe from 2012 on reaching 5.5 Mtoe in 2021. The sector depends almost exclusively on liquid fuels (about 96% in 2021) and therefore poses particular challenges for the decarbonization of the sector, which is critical for achieving net-zero emissions by 2050.

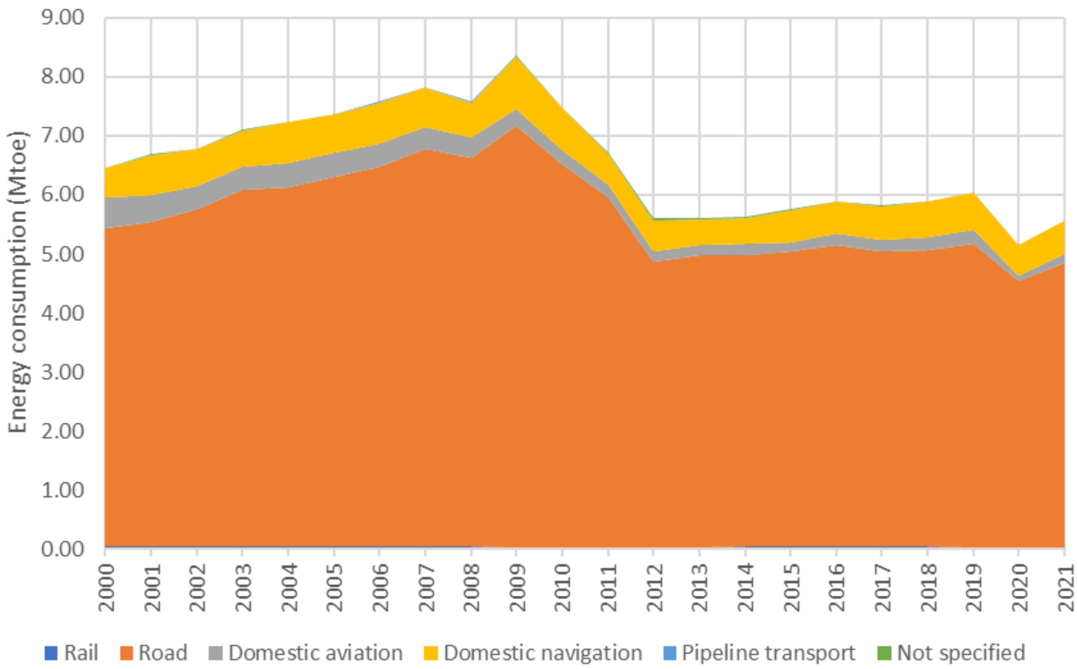


***Figure 5**: Final energy consumption in the transport sector in Greece for the period 2000-2021 (Mtoe). Source: Eurostat, [nrg_bal_s].*

Road transport dominates energy consumption in the transport sector as it accounts for about 87% of sectoral final energy consumption in 2021 (from 83% in 2000). In total, energy consumption in road transport decreased from 5.4 Mtoe in 2000 to 4.8 Mtoe in 2021. From 2000 to 2009 energy consumption was increasing with various fluctuations reaching a value of 7.1 Mtoe in 2009. Then, for the next five years, in the heart of the financial crisis that hit the Greek economy in the 2010s, energy consumption decreased to 4.9 Mtoe in 2014. Since then, a slow increasing trend was observed that was interrupted in 2020 mainly due to the pandemic mobility restrictions. It is noted that consumption levels since 2014 remained below those in the 2000s probably due to socioeconomic reasons (e.g., reduced income) but also due to the improved efficiency of newly registered vehicles.

Within road transport, the segment of passengers' transport is the most significant (compared to freight road transport that is covered almost exclusively by trucks) as its contribution (including railways) ranges from 62% to 70% of the total road transport energy consumption (65% in 2021). Energy consumption for road passenger transport presents a similar trend to the one described above for road transport. Energy consumption decreased only slightly from 3.4 Mtoe in 2000 to 3.2 Mtoe in 2021, reaching a maximum value of 4.4 Mtoe in 2009 (**Figure 6**). In addition to the socioeconomic developments, the improvements in the fuel economy of vehicles have contributed to the observed trend.

This energy consumption trajectory is also reflected in **Figure 7**, which shows the evolution of CO_2 emissions from the passengers' transport segment of road transport and railways. Practically, all emissions derive from fuels use (i.e., direct emissions). Emissions reduction for the period 2009 – 2021 (4.2 Mt CO_2) is significantly larger than the increase in the period 2000 – 2009 (3.1 Mt CO_2). The emissions trend is similar to the energy consumption trend. Emissions from passengers' transport have remained almost stagnant between 2013 and 2021 (around 9.6 Mt CO_2) with the exception of 2020, the year of the covid pandemic when they dropped to 8.1 Mt CO_2, and emissions in 2021 were about 11% lower compared to those of 2000.

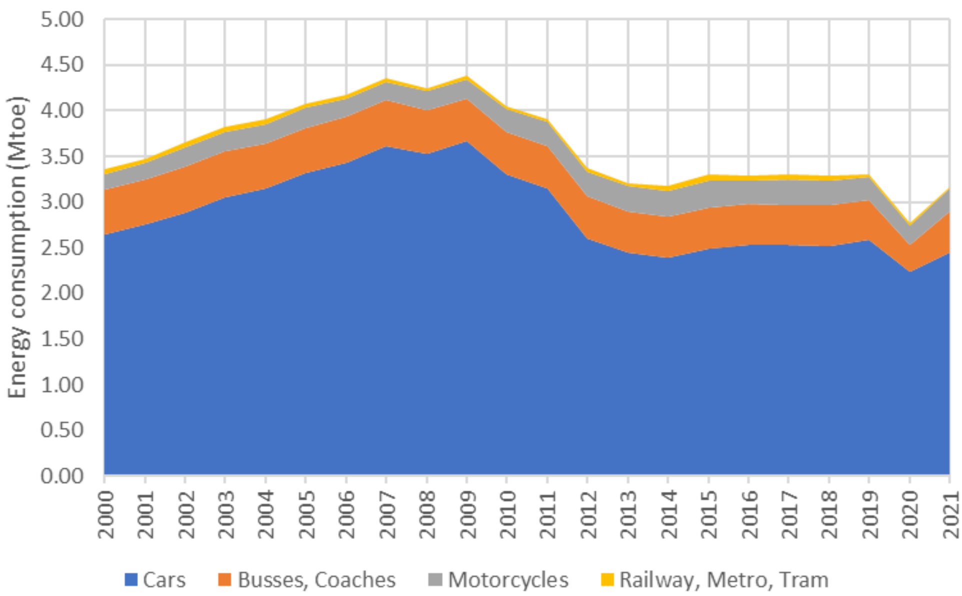


Figure 6: *Final energy consumption for passenger transport (road transport and railways) in Greece for the period 2000-2021 (Mtoe). Source: National GHG emissions inventory, April 2023.*

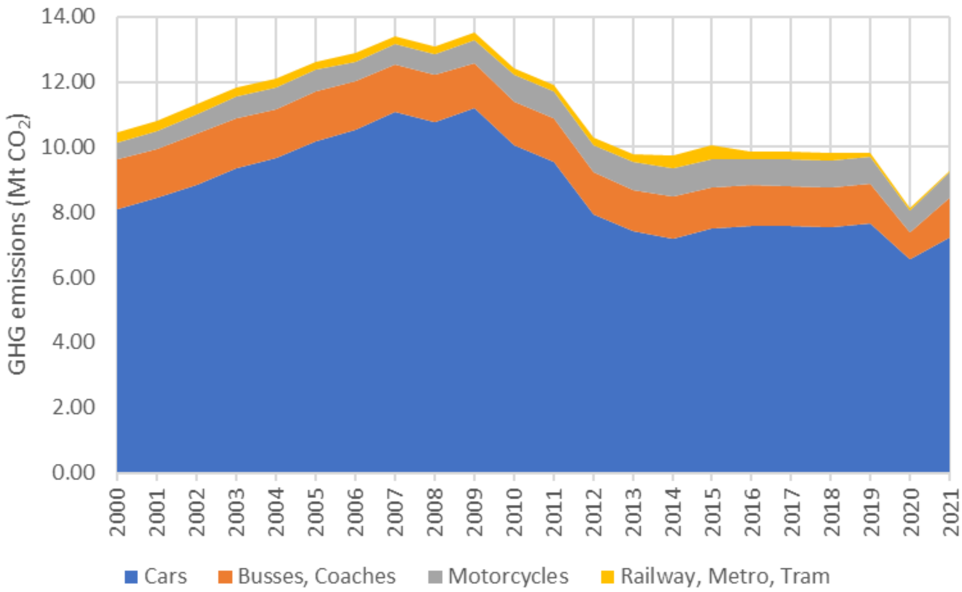


Figure 7*: CO_2 emissions from passenger transport (road transport and railways) in Greece for the period 2000-2021 (kt CO_2). Source: National GHG emissions inventory, April 2023.*

A more detailed analysis[2] of the parameters influencing the change in the carbon footprint of the passengers' transport segment of road transport and railways in the period 2000-2020[3] is shown in **Figure 8**. The total reduction in emissions amounts to 22% or 2.3 Mt CO_2. The enhanced activity in terms of passenger kilometers[4] (up by 26% in 2020 from 2000) resulted in an increase of emissions by 2.1 Mt CO_2. Modal shift (in terms of the share of passenger-kilometers driven by different transport modes) has also had an increasing effect (0.4 Mt CO_2) as the share of passenger kilometers driven by passenger cars increased from 64% in 2000 to 80% in 2020. Both effects are compensated for by improvements in the fuel economy of vehicles stock (- 5 Mt CO_2). A part of these reductions (about 0.6 Mt CO_2) is lost as actual driving behavior is far from the optimal conditions assumed when deriving announced fuel economy values. Finally, the reduction of the carbon content of the fuels used (e.g. through the introduction of fossil gas mainly in buses and biofuels blended in diesel and gasoline) contributed an additional reduction 0.5 Mt CO_2.

[2] A decomposition analysis based on the LMDI method, first introduced by Ang and Liu (2001) has been implemented. As explanatory variables the number passenger-kilometers driven, the share of passenger-kilometers per transport mode (model shift), the technical efficiency of vehicles, behavioral changes and the carbon intensity of energy sources used have been used. The data were derived from Eurostat, IDEES database, the Hellenic Statistics Authority, and the National GHG emissions inventory submitted to the UNFCCC (2023).

[3] Data on passenger kilometers were not available for 2021.

[4] Transport in Figures 2022, Directorate General for Mobility and Transport in cooperation with Eurostat (https://transport.ec.europa.eu/facts-funding/studies-data/eu-transport-figures-statistical-pocketbook/statistical-pocketbook-2022_en).

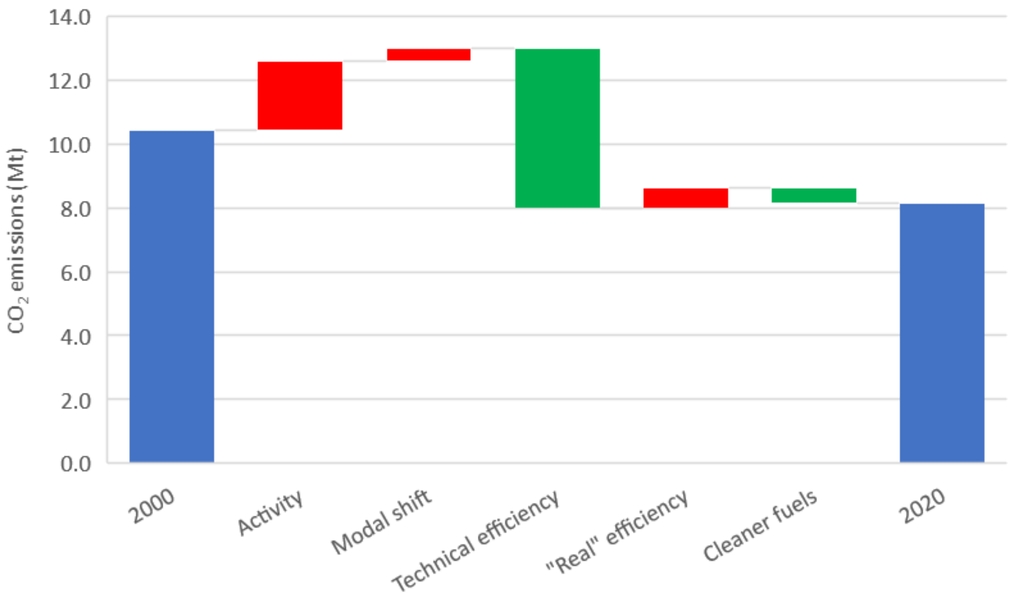


***Figure 8**: Decomposition of the evolution of the CO2 emissions from the passengers' transport segment of road transport and railways in the period 2000-2020.*

In summary, for the period 2000 – 2020, changes in emissions from passengers' transport are attributed to two opposite trends: on the one hand the increased activity and the intensified use of passenger cars increased emissions, whereas the improvements in fuel economy of the vehicle stock led to emissions cuts. The enhancement of the electrification of the vehicles' fleet in conjunction with the continuous reduction in the carbon footprint of the electricity generation sector are expected to further contribute to cutting the GHG emission of the road transportation sector in the future. At the same time, policies to promote non-technical measures targeting activity and behavioral changes are necessary to address the parameters that lead to increased energy consumption and emissions.

1.4 Recent, on-going and announced support measures

In view of the targets that all MS had to take to meet the ambitious EU targets for 2030 for GHG emissions and energy efficiency in the scope of the EU Green Deal, Greece had already put in place policies and measures aiming at reducing energy use and emissions in both the residential and transport sectors. In the residential sector the "Exiconomo at home II" (Conserve at home), a sequel to an earlier (2009) energy upgrading program, was implemented in 2018 to be followed by new versions in 2021 (Exiconomo 2021 and Exiconomo-Autonomo). Those programs provided grants as well as low interest loans for ca 140,000 renovations. With the enhancement of targets in the "Fit for 55" package, a new version of "Exiconomo 2023" and a new program "Exiconomo-Anakainizo" for young couples, were announced with a total public funding of € 300 Mil until 2025 and a target of upgrading an additional ca 105,000 buildings/dwellings.

Additionally, in the last year the government has put in place a policy to facilitate the replacement of older, less efficient household appliances (refrigerators and air conditioners) with new ones. The program budget now stands at € 287 Mil and will provide subsidies to over 425,000 recipients.

A subsidy program for the installation of rooftop PV with battery storage is also ongoing with a budget of € 208 Mil. More than 5,000 installations have already been approved for grants although administrative problems have been reported resulting in over 50% of planned PV rooftop installation applications not participating in the program.

In the transport sector, a subsidy program providing grants covering 30% of the purchase price (up to a maximum of € 9,000 per vehicle) of Battery Electric Vehicles (BEV) including scooters and bicycles has been in place for over two years totaling ca € 50 Mil, which,according to the Ministry of Environment and Energy, involving sales of over 10,000 2 and 4 wheelBEVs representing ca 2.5-3% increasing to 4% in 2023 of total sales.

These figures are to be juxtaposed with the corresponding ones inscribed in the Greek NECPs. The current NECP submitted in December 2019 is to be superseded by the new one announced in January 2023 in a slide deck form of 51 slides and again in August 2023 in an abridged form of a 75-page text which was put out for consultation to a limited group of stakeholders but not to the general public. Finally on 6 November, the Greek government submitted to the EC a new version of the revised draft NECP.[5]

The marquee targets of the November 2023 NECP are summarized in the following **Table 1**.

***Table 1**: The November 2023 NECP targets for GHG emissions reduction, RES penetration and energy efficiency.*

NECP Targets	2021	2025	2030	2035	2040	2045	2050
GHG emissions Reduction wrt 1990 wo /LULUCF	-26%	-41%	-54%	-68%	-82%	-89%	-93%
GHG emissions Reduction wrt 1990 with /LULUCF		-44%	57%	72%	87%	-95%	-99%
RES in GFEC	35%	31%	44%	65%	83%	97%	105%
Energy Efficiency		-4%	-5%	-14%	-18%	-22%	-27%
FEC (Myoe)	15.65	16.60	15.40	13.80	12.80	12.00	11.50
RES in electricity production	36%	58%	79%	94%	96%	96%	97%
RES in heating/cooling	31%	36%	46%	63%	80%	99%	100%
RES in Transport	4%	13%	29%	98%	209%	381%	584%
RFNBO (% in Transport)		0%	1%	11%	23%	31%	50%
Advanced biofuel (% in transport)	0%	0%	2.4%	10%	17%	26%	32%
Conventionsl biofuel (% in transport)	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%	1.7%
Non-ETS GHG emissions reduction	-32%	-36%	-46%	-61%	-76%	-84%	-87%

[5] https://commission.europa.eu/publications/greece-draft-updated-necp-2021-2030_en

The available information from the November NECP (actually April) versions for the residential and transport sectors is given in **Tables 2 and 3** below.

Table 2: *Information relevant to the residential sector in Greece in the 2023 NECP.*

Demographics	**2010-15**	**2015-20**	**2020-25**	**2025-30**	**2030-35**	**2035-40**	**2040-45**	**2045-50**
Population (Mil)		10.70	10.51	10.30	10.11	9.91	9.71	9.50
GDP (M€2015)	177.26	168.17	194.85	200.43	212.35	231.16	251.17	272.06
Residential								
Total household expenditure (Bil€)	123.10	115.00	132.40	135.40	142.60	154.20	166.60	179.30
Households	4375.00	4382.00	4371.00	4336.00	4313.00	4294.00	4285.00	4274.00
Household size	2.44	2.44	2.40	2.38	2.34	2.31	2.27	2.22
Household space (m2/hh)	88.00	88.00	89.00	90.00	90.00	91.00	91.00	92.00
Residential space (Mm2)	385.00	385.62	389.02	390.24	388.17	390.75	389.94	393.21
Renovation - New construction								
Renovation rate % of total	3	7	12	19	25	31	38	43
Buildings w/o renovation(1000)		3620	3212	2715				1256
Renovation (1000/yr)		47	59	79				83
Renovation rate yearly %		0.8	1.0	1.4	1.7	1.5	1.6	1.7
Renovation cost (MEUR) 5-yr average		362	483	811	855	707	716	694
New construction (%/yr)	0.07	0.11	0.15	0.18	0.21	0.23	0.25	0.27
Equipment & Appliances								
Appliances (1000)								
White	10170	14026	15750	17339	18860	20120	20783	21226.00
Black	24587	33013	38953	45975	50162	58751	63199	64284.00
A/C	3631	5460	8351	10935	13665	17175	20568	21857.00
Appliance efficiency (kWh/app)								
White	301	247	148	144	142	139	135	130
Black	249	234	212	192	179	171	167	164
A/C		337	229	169	140	120	112	113
AC/ COP	2.45	3.03	3.64	4.31	4.73	5.08	5.2	5.3
Buildings with HP (1000)		351.3	519.3	856.6				2727.4
% building with Heat pumps for heat/cool		8	12	17	34	53	71	91
Purchase of equipment (5yr ave) Mil€		2877	5752	6174	4796	5005	4098	5532
Energy consumption								
% electricity to FEC		36	38	47	53	56	59	61
Average energy consumption (kWh/m2)	135	135	128	112	101	98	94	90
Emissions								
Total emissions All Buildings,& Agri MtCO2	6.3	5.6	5.3	3.7	1.9	1.1	0.1	0
Emissions from Res Buildings tCO2/toe		1.11	1	0.69	0.29	0.1	0.01	0.01

As shown in Table 2, the population is decreasing over the whole period 2020-2050, at an almost constant rate. This results in an almost constant amount of the total number of buildings, a small decrease in the household size and a similarly small increase of space per household. In the 2020-2030 time slot these changes in demographics are less than 2%.

Focusing on the 2020-2030 period, the NECP calls for an 11.9% decrease in the FEC. This is to be accomplished by (i) building energy upgrading with an annual rate of 58,000/yr in the 2020-2025 period which is planned to increase to 68,000/yr in the next 5-year period 2025-2030, (ii) by increasing the share of heat pump use by 9% from 7% in 2020 to 17% of the total by 2030 and (iii) upgrading for the household appliances by increasing their efficiency from an average of 40% of white appliances and 20% for black appliances.

To accomplish this, an amount of € 2.5 Bil for the 2020-2025 period to increase by an additional € 4.1Bil for the next 5-yr period 2025-2030 will be required for renovation. The corresponding emissions reduction in the 10-yr 2020-2030 period is estimated at ca 500 kt CO2 or 9% of the total residential sector emissions. A much larger amount of € 43.9 Bil is budgeted for the purchase of high efficiency appliances for the same 10-yr period.

Moreover, the NECP calls for an increase of PV installed capacity by 9.1GW in the 10-yr period 2020-30. Of those, 100,000 rooftop installations are now inscribed in the program for subsidies. Following the costs referred to in the current subsidy program as a guide (i.e., € 1500/kW plus € 850/kWh for the accompanying battery pack) and assuming an average capacity of 5kW per installation as well as an additional 20% of installations that would not take advantage of the subsidy (40% in September 2023) this would require an investment of ca € 1.32 Bil of which ca. €645Mil is the subsidy amount.

As shown in Table 2, there are some notable differences between the versions of the 2023 NECP. The first is the huge increase in heat pump installation after 2030 which in 2050 reaches almost 100% in the August 2023 version (albeit with the same emissions and the same energy consumption per m^2). The second is the large decrease (of the order of 25%) in expenditures for renovation in the 2021-2025 period in the November 2023 version which is much closer to the actual one as at the time of this writing we are already half-way into the 5-yr period.

In the transport sector (Table 3), the NECP calls for a reduction of emissions in the 10-yr period to 2030 by about 2 Mt CO2. This is to be accomplished mainly by increasing the proportion of PHEVs and BEVs in the new car sales and the higher efficiency of the fleet as older vehicles are replaced with new more efficient ones. The current (November 2023) share of of PHEV/BEV in new car sales stands at 9.0%, (i.e., 26,000 vehicles of which 11,500 BEV) which is not in line to meet the 19% target (i.e., 78,000 of which 35,000 BEV vehicles) for the 5-yr period 2020-25 inscribed in the NECP (see Table 3). Still the 50% target (i.e., 430,000 vehicles of which 256,000 BEV) of new car sales by 2030 seems ambitious but possible.

Table 3: Information relevant to the transport sector in Greece in the 2023 NECP.

Passengers & Freight	2020	2025	2030	2035	2040	2045	2050
Energy consumption Cars & 2W (Twh)	51.31	55.02	48.06	38.91	29.30	22.29	18.04
Energy consumption Public road transp (TWh)	4.27	4.31	4.31	4.11	3.49	2.99	2.76
Energy consumption Rail (TWh)	0.29	0.51	0.55	0.53	0.52	0.50	0.48
Energy consumption Air (TWh)	9.86	13.94	14.74	15.97	16.49	17.11	18.25
Energy consumption IWW (TWh)	6.69	6.05	6.69	6.57	6.34	6.28	5.88
Electricity Road transport (TWh)	0.02	0.19	1.41	3.63	6.00	8.62	9.89
Total Emissions w/o int. maritime (MtCO2)	16.1	19.2	17.0	11.5	5.9	3.1	0.5
Passengers							
Passenger activity (Gpkm)	148	201	218	241	247	252	263
Passenger activity (Gpkm) -Extra EU Air	136	174	186	204	205	207	214
Aviation dom &intra EU (Gpkm)	12	30	31	35	37	40	45
Passenger Road activity (Gpkm)	118	135	144	158	158	155	157
Passenger activity- electric as % of all	0.0	2.9	20.4	49.8	71.6	86.8	97.6
Rail passenger (%)	1.3	1.8	1.9	1.9	2.1	2.4	2.5
% BEV PHEV Total Fleet Cars	0.1	2.1	18.5	38	55.9	69.7	80.5
% BEV PHEV new sales cars	0.3	19.0	50.0	80.1	72.1	81.5	85.6
% BEV PHEV new sales all w/o trucks	0.0	6.0	33.0	78	75	79	83
% H2 new sales				7	31	27	23
Car spec consum eff MJ/km	2.69	2.51	1.94	1.4	1	0.75	0.55
Car Passenger spec consum eff MJ/pkm	1.32	1.23	0.95	0.68	0.48	0.36	0.27
Passenger spec consum eff MJ/pkm	1.29	1.16	0.98	0.80	0.65	0.56	0.49
Total expenditure for transport vehicles (M€)	10879	10904	15618	13234	15194	15765	16719

The NECP calls for a total annual expenditure for all means of transportation of €10.9 Bil in the 2020-25 period and € 15.62 Bil in the 2025-2030 period for a total of € 132.6 Bil for the 10 yr period to 2030.

No significant increase of the very small rail transport share of less than 2% is envisioned even though the total passenger kilometers (pkm) as well as the road activity pkm are estimated to increase by about ca 9% by 2030.

The data for the transport sector from the November 2023 version of the NECP seem to contain a contradiction as the pkm with electric vehicles are reported at 97.6% by 2050 while at the same time the new car sales of non-electric vehicles are at 17%.

2. Methodological framework and main assumptions

2.1 Analytical aspects (bottom-up engineering models)

The analysis was conducted using bottom-up engineering models developed in this project, through which the energy consumption and the resulting GHG emissions in the sectors of residential buildings and passenger land transport in Greece are estimated in detail.

In general, bottom-up models have a detailed representation of the technical factors determining the emissions associated with the sector under consideration and incorporate engineering data and technological choices. For example, the bottom-up models for the buildings sector usually include a detailed representation of the building stock, which is usually disaggregated into several buildings' categories based on their use (i.e., residential buildings and commercial buildings, with additional disaggregation), their energy class, their geographical location, etc. In addition, for each building category energy consumption is farther disaggregated per main energy use and energy sources used. Correspondingly, a bottom-up model for passengers' transport includes a disaggregation of the transport activity per mode of transport, a detailed representation of the vehicles stock and its energy performance, as well as the energy sources used. These models provide a good basis for assessing sector-specific policies and measures. Specifically, they are appropriate to assess command and control policies, as well as the technical and economic mitigation potential at sectoral level (Oeko 2008), (Swan & Ugursal, 2009), (Hall & Buckley, 2016), (Bourdeau et al., 2019). On the other hand, their capability for analyzing wider economic policies and their feedback to the rest of economy is limited.

Focusing on the buildings sector, one has to take into account that a detailed assessment of the various low carbon measures needs a disaggregated classification of buildings, while at the same time the various characteristics of the building stock need to be accurately represented. Therefore, within the model developed for this study, residential buildings are classified based on their energy class, distinguishing 9 different types of dwellings. The classification was made considering the period of construction of these buildings as well as statistical data on the energy performance of dwellings built in the respective period, published annually by the Ministry of Environment and Energy. The energy consumption in each category of dwellings was simulated across six end-uses, namely: (i) space heating; (ii) hot water; (iii) space cooling; (iv) cooking; (v) lighting, and (vi) electrical appliances (further disaggregated in laundry machines, dish washers, refrigerators and freezers, TV and multimedia, ICT and other micro appliances). The energy demand in each end-use was calculated by applying analytical methodologies using typical meteorological data and other existing information and data from national/international sectoral studies regarding unit consumption/efficiency (e.g., IDEES database[6], the Clever Scenario for Europe developed by NegaWatt Association[7], etc.). The shares of technologies and fuels (e.g., central space heating systems, wood-fired boilers, solar systems for hot water, etc.) represent the main modelling parameters.

For passengers' transport the model includes the available transport modes (passenger cars, motorcycles, buses & coaches, metro and railway), the available technology options per transport mode together with the expected improvements on vehicle efficiency and the fuels used in each case including their biofuels share as applicable (only blended biofuels considering the time horizon of the analysis). Energy consumption is calculated based on vehicle stock per mode and category, its average efficiency and mileage. The introduction of the mileage parameters (by means of passenger kilometers, (pkm) allows for the examination of non-technical measures (e.g., soft mobility) as well as for the substitution between transport modes. Input information derives from national and international databases and sectoral studies (e.g., IDEES database, the Clever Scenario for Europe developed by NegaWatt Association, etc.).

The model developed for the residential sector covers the entire period 2015-2050, while the present study focuses on the decade 2020-2030. For the historical years of the analysis, namely the period 2015-2021 for which the energy balances have been published, a comparison of the model results with the energy balance data was attempted and the appropriate adjustments were made. For the transport sector, the disaggregated consumption figures available in the National Emissions Inventory Report are also considered for calibrating the model. Following model calibration utilizing the historical years, estimates of the energy consumption were made for each year of the period 2022-2030 by taking into account the following:

- For the residential sector: the population evolution, the evolution of the average household size, assumptions about the degree of penetration of various technologies and appliances in Greek households, and changes in households' behaviors regarding the degree and manner of use of various technologies and services linked to energy consumption.
- For the transport sector: the evolution of vehicles stock (for passenger cars and motorcycles), the evolution of transport activity by means of passenger kilometers, assumptions about the degree of penetration of various passenger cars, and changes regarding transport mode selection by households and expected improvements in technical efficiency.

These constitute the reference state to be compared with the results of the application of the mitigation measures under consideration for proposed adoption.

[6] Mantzos, Leonidas; Matei, Nicoleta Anca; Mulholland, Eamonn; Rózsai, Máté; Tamba, Marie; Wiesenthal, Tobias (2018): JRC-IDEES 2015. European Commission, Joint Research Centre (JRC) [Dataset] doi: 10.2905/JRC-10110-10001 PID: http://data.europa.eu/89h/jrc-10110-10001

[7] https://clever-energy-scenario.eu/

2.2 Mitigation measures examined, and scenarios evaluated

The analysis is based on 12 mitigation actions aiming at reducing the GHG emissions from energy consumption in residential buildings and 6 interventions aiming to improve the carbon footprint of passengers' transport (see **Table 4**). All these interventions can be classified in three main categories, namely **sufficiency** measures involving mostly changes in the energy consumption behavior aiming at reducing energy demand, **efficiency** measures aiming at improving energy and material intensities, and increased use of **renewables** in order to reduce the carbon intensity of the energy mix used in the sectors in question. **Table 4** presents more detailed information about the measures under consideration, the main assumptions adopted for the assessment of energy savings and the emissions reduction potential, as well as their maximum penetration levels. The assumptions made for each measure take into account the characteristics of the building and vehicle stock, the wider conditions of the Greek economy, but also possible barriers that hinder their effective implementation. It is also worth mentioning that the analysis does not include structural sufficiency measures (for example the implementation of policies aimed at promoting living in smaller homes with a floor space between 35 and 40 m^2 per capita) due to the short-term nature of the analysis recognizing that such interventions require long-term planning. However, such measures should be evaluated in the context of long-term energy planning. In addition, potential infrastructure investments for road transport are not part of the analysis as it is assumed that they will be covered in the context of the policies announced and included in the NECP (e.g., charging stations for electric vehicles). It also noted that considering the current share of public transport is small, and the time horizon of this study is short, we did not include in this analysis ambitious measures enhancing public transport which, in order to be effective, require more longer-term policies.

***Table 4**: The mitigation actions examined in the context of this study with the maximum penetration rates considered based in experts' judgement.*

Type of measure	Measure	Penetration		Comments
		2025	2030	
		Residential buildings		
Sufficiency	Adjusting the heating set point for homes	2023: 10% of hh 2024: 20% of hh 2025: 30% of hh	60% of hh	To 19ºC from 20ºC Heating reduction by 12% based on the difference of HDDs.
	Adjusting the cooling set point for homes	2023: 10% of hh 2024: 20% of hh 2025: 30% of hh	60% of hh	To 27ºC from 26ºC Cooling reduction by 22% based on the difference of CDDs
	Reduce temperature by 2ºC when absent and at night	2023: 10% of hh 2024: 20% of hh 2025: 30% of hh	60% of hh	Influences only heating. Heating reduction by 16% based on the difference of HDDs and the hours of absence
	Switching off standby and unnecessary devices	2023: 15% of hh 2024: 30% of hh 2025: 50% of hh	90% of hh	It is assumed that the annual electricity consumption in standby mode in Greece reaches 279 kwh/hh (Balaras et al. 2013)
	Smarter settings for household appliances	2023: 5% of hh 2024: 15% of hh 2025: 25% of hh	50% of hh	Better filling and choice of the most energy efficient programs in washing machines. 25% reduction in hh electricity consumption for using this appliance.
Efficiency	Deep renovations	80,000 hh/y	80,000 hh/y	All renovated buildings will be upgraded to B+. In total 560,000 hh will be renovated (in NECP 525,000 hh the period 2021-2030)
	Shallow renovations	100,000 hh/y	100,000 hh/y	All renovated buildings will be upgraded by 3 energy classes. In total 700,000 hh will be renovated (in NECP 525,000 hh the period 2021-2030)
	Heat pumps	2023: 25% of hh 2024: 29% of hh 2025: 33% of hh	53% of hh	Market technology.
	Installation of insulating films on single glazing	2023: 5% of hh 2024: 10% of hh 2025: 15% of hh	40% of hh	3-4% reduction in heating consumption (nW)
	Substitution of the last inefficient light bulbs	2023: 50% of remaining hh 2024: 75% of remaining hh 2025: 100% of remaining hh	Already considered 100%	
Renewables	Solar thermal for hot water	2023: 60,000 sys. 2024: 120,000 sys. 2025:180,000 sys.	500,000 systems	They concern additional systems to those already existing.
	Installation of PV	62,500 hh/y	62,500 hh/y	4kW per hh. This means that in 2030 there will be an additional 500,000 hh with PV, i.e., 2 GW of PVs.
		Passenger transport		
Sufficiency	Reduction of the maximum speed limit on motorways	In 100% of motorways and expressways transport activity of passenger cars (gasoline and diesel)		Limit: 110 km/h in motorways and 100 km/h in expressways. 20% reduction of fuel consumption in the journeys concerned (based on nW)
	Soft mobility	2025: 5% of pkm	2030: 7% of pkm	The shares refer to total number of pkm excluding railways, air and maritime transport (based on nW).
	Teleworking	2024: 1% of the employed population. 2025: 2% of the employed population.	5% of the employed population.	2021: 43.3% of the total population is employed (ELSTAT). The share is kept constant. Assumption: each employee travels 20km/d for 240 d/y.
	Public transport (rail and metro)	2025: 25% increase of the pkm travelled with metro/tram	2030: 50% increase of the pkm travelled	The increased shares of public transport will substitute transport with private cars.

Type of measure	Measure	Penetration		Comments
		2025	2030	
			with metro/tram	
	Carpooling	2025: Applied to 5% of employees	2030: Applied to 10% of employees	Assumptions as above in Teleworking. Fewer vehicle kilometers (v-km) for the same transport activity (p-km)
Efficiency	Electric vehicles	2025: 2.1% of the passengers' vehicles stock	2030: 18.5% of the passengers' vehicles stock	Based on the results of the 2019 NECP. All electric vehicles are BEV.

As already mentioned, the main objective of this study is to investigate what measures may be implemented by Greek households to meet their energy needs under conditions of high fossil gas, oil and electricity prices, and simultaneously to reduce their carbon footprint, thus contributing to the achievement of the national climate targets.

As regards energy consumption and the resulting GHG emissions in residential buildings, the policy questions of the analysis are further elaborated as follows:

- To what extent the promoted electrification of thermal uses (mainly with heat pumps) and the penetration of more efficient devices should be coordinated and combined with the energy upgrade of the existing building stock, which is time-consuming and requires the commitment of significant resources?
- In the case that the energy upgrading of the building stock is deemed necessary, relevant policies should focus on shallow energy renovations in a greater number of dwellings or on deep renovations, which due to budget restrictions will be implemented, at least in the short run, in a smaller number of homes?
- To what extent energy sufficiency and behavioral change measures can contribute to reducing energy consumption and the associated GHG emissions?
- Is it cost-effective for the energy savings measures in buildings to be accompanied by the installation of small-scale renewables (mainly photovoltaics) to cover the electricity needs of households either individually or collectively through energy communities, or would it be preferable to focus solely on the decarbonization of the power sector using large-scale renewables by the utilities and other commercial entities?

All these policy questions were explored through scenario analysis with the bottom-up engineering models that were developed for this purpose. Each scenario incorporates a different set of mitigation measures chosen from those presented above in Table 4, in a way that possible synergies from their simultaneous implementation are assessed.

In total, eight different scenarios for the residential sector were developed, and are described as follows:

- S0 assumes a strong penetration of easy to implement efficient and clean technologies, including heat pumps, solar systems for hot water, efficient lighting, and insulating films.
- S1 is based on S0 with the additional incorporation of the sufficiency interventions presented in Table 4.
- S2 focuses on shallow renovations of approximately 100,000 dwellings per year and simultaneously comprises all the interventions included in S0 and S1. In this context, the new heat pumps installed are resized due to the reduced energy demand attributed to the energy renovation of the dwellings.
- S3 is like S2 including deep instead of shallow renovations in a slightly lesser number of dwellings (80,000 homes on an annual basis until 2030).
- In S0-PV – S3-PV (4 scenarios) the installation of 2 GW of photovoltaics is added to the packages of interventions included in each of the scenarios S0 – S3.

With respect to road transport the policy questions of the analysis are further elaborated as follows:

- To what extent the electrification of vehicles fleet should be accompanied with measures that aim at improving driving behaviour or even at reducing transport activity (passenger kilometers)?
- To what extent energy sufficiency measures can contribute to reducing energy consumption and the associated GHG emissions?
- What are the linkages between measures in the residential and transport sectors, considering the restriction of households' budget?

A similar to the residential sector approach was followed to address the above-mentioned issues. Two scenarios have been developed and are described as followd:

- T1 only considers the electrification of the vehicle fleet, as defined in Table 1.
- T2 assumes that both the electrification of the vehicles fleet and the whole set of sufficiency measures included in Table 1 are implemented. Compared to T1 scenario, the number of electric vehicles introduced is the same but with lower mileage per vehicle.

2.3 Criteria for scenarios evaluation and identification of the needs for support policies

The main assessment criteria used for the evaluation of the scenarios developed include:

<u>Effectiveness in reducing GHG emissions:</u> For each scenario, the amount of GHG emissions saved as a result of the mitigation measures included, is estimated in relation to the sectoral emissions of the base year of the analysis (i.e., 2022), which, due to the relatively short period of the analysis, corresponds to a Reference Scenario where future energy demand is covered mainly with existing technologies

and fuels. The amount of GHG emissions saved are estimated on a yearly basis, further disaggregated to direct (scope 1) and indirect (scope 2) emissions. Scope 2 emission savings are estimated taking into account the changes in electricity consumption compared to the base year and the decarbonization plan of the power sector included in current NECP adopted in 2019.

Cost-effectiveness: The economic evaluation of each scenario comprises the following steps:

- Definition of technical parameters and evaluation assumptions: Based on the results obtained from the utilization of the energy model, the technical characteristics of each scenario (e.g., penetration of each distinctive measure, total fuel savings, etc.) are specified. In addition, a discount rate on the basis of which the economic analysis will be performed, is selected.
- Definition of private cost and benefits components: In this step, all costs and benefits associated with the implementation of each scenario, which influence its financial return, are specified. These typically include initial (investment) expenditures, maintenance and operation cost, and revenues from fuel and electricity savings.
- Calculation of the net annual cost: In this step, the initial cost IC is annualized over the entire lifetime T of the measures included in the scenario by applying the following equation:

$$AIC = \frac{IC \times r}{(1 - (1 + r)^{-T})}$$

where AIC is the annualized initial cost (EUR/y) and r is the discount rate (%). Then, the annual net cost ΔC is calculated by subtracting from the sum of the annual operational and maintenance costs (OMT which include the fuel and electricity costs) and the annualized initial cost of the year in question (AIC), the annual operational and maintenance cost of the base year (OMB):

$$\Delta C = AIC + OMT - OMB$$

Furthermore, for facilitating the comparative evaluation of the alternative scenarios we also used two additional economic indicators:

- In order to take into account both the net annual cost and the GHG emission reductions achieved, the net cost per unit of CO2eq emissions reduction (EUR/t CO2eq) for each scenario has been calculated by dividing the annual net cost ΔC with the net annual emission reduction ΔEm (as estimated by the bottom-up energy model).
- As upfront cost is one of the most important barriers faced by households in order to implement even cost-effective interventions, the total investment cost required for the realization of the interventions included in each scenario throughout the reference period (i.e., 2023-2030) is also considered in evaluating the scenarios.

2.4 Main economic assumptions and sensitivity analysis

The results of the analysis are significantly affected by the economic assumptions adopted, namely unit investment costs for each intervention, fuel and electricity prices and the discount rate adopted.

Table 5 summarizes the investment costs of the various GHG emission reduction interventions incorporated in the scenarios developed for the residential sector. The data presented concern the total investment cost of each intervention and do not take into account any subsidies or other supporting policies applied by the Greek State.

Table 5. *The mitigation actions included in each scenario for the residential buildings and their investment cost. Sources for investment costs: Deep renovations: BPIE (2020); Shallow renovations: NECP (2023); Heat pumps: Technical Guide of the program "Saving – Renovate for Young"; Insulating films: market research of the Project Team; Efficient lighting: https://www.effiworkx.com/calculators/electricity-calculators/led-bulb/; Solar thermal systems: Technical Guide of the "Recycle - Change Water Heater" program; PV: Technical Guide of the "Rooftop Photovoltaics" program.*

Mitigation actions	Investment costs	Measures' incorporation in the scenarios examined							
		S0	S1	S2	S3	S0-PV	S1-PV	S2-PV	S3-PV
Adjusting the heating set point for homes	4,000,000 EUR/y in trainings and informative campaigns		X	X	X		X	X	X
Adjusting the cooling set point for homes			X	X	X		X	X	X
Reduce temperature by 2°C when absent and at night			X	X	X		X	X	X
Switching off standby and unnecessary devices			X	X	X		X	X	X
Smarter settings for household appliances			X	X	X		X	X	X
Deep renovations (EUR/dwelling)	29,904				X				X
Shallow renovations (EUR/dwelling)	15,650			X				X	
Heat pumps (EUR/kW)	400	X	X	X	X	X	X	X	X
Installation of insulating films on single glazing (EUR/dwelling)	725	X	X	X	X	X	X	X	X
Substitution of the last inefficient light bulbs (EUR/W)	0.5	X	X	X	X	X	X	X	X
Solar thermal systems for hot water (EUR/dwelling)	1,550	X	X	X	X	X	X	X	X
Installation of roof-top PV (EUR/kW)	1,800					X	X	X	X

For road transport, the following assumptions were made with respect to the cost of the measures.

- For all sufficiency measures a total annual cost of 4 million EUR (2024 – 2030) for awareness campaigns was assumed on the basis of relevant provisions in funding programs currently implemented.
- The cost of purchasing an electric vehicle (BEV) was taken to be 35,000 EUR per vehicle (consumer price without considering any subsidies or other support policies) for the whole period, considering the technical guide of the "Kinoume Hlektrika" project[8].

A critical parameter for the overall economic performance of the scenarios analyzed is the energy prices and how they are expected to evolve during the analysis period. In general, high-energy prices favor the implementation of energy savings measures and contribute to shortening the payback period of the required investments. In the context of this study, the main set of results assumes relatively high energy prices as they were in late 2022, when the much higher energy prices recorded earlier that year due to the Russian war on Ukraine, had started to de-escalate. In order to assess the effect of energy prices on the results of the analysis, all scenarios were re-evaluated with a set of low energy prices, that is assuming that fuel and electricity prices return to 2017 levels. Finally, the calculations were repeated for a third set of moderate energy prices. In this scenario, electricity and fuel prices were initially set as the means of the low and high prices considered previously. However, fossil fuels prices were increased compared to these levels by half of the emissions cost (50% pass through) due to the operation of the new EU Emissions Trading System for buildings and transport (ETS2) which, according to the recently revised EU ETS Directive, will come into effect in 2027. **Table 6** summarizes the three different sets of fuel and electricity prices adopted for the economic evaluation of the scenarios.

Table 6*: Assumptions for the energy prices adopted in the context of this analysis (€/MWh). The prices remain constant for the entire period 2023-2030.*

Energy carrier	**Set of high energy prices**	**Set of low energy prices**	**Set of moderate energy prices considering the operation of ETS2 in buildings and transport starting in 2027**
Residential buildings			
Solid fuels	82	43	71
Oil products	118	97	114
Fossil gas	174	77.4	130
Biomass	82	43	63
Electricity	265	153	209
Heat	40	40	48
Passenger transport			
Gasoline	223	164	178

[8] An initiative of the Hellenic Government to promote vehicles' electrification, including charging, and sustainable mobility.

Energy carrier	Set of high energy prices	Set of low energy prices	Set of moderate energy prices considering the operation of ETS2 in buildings and transport starting in 2027
Diesel	184	124	142
Electricity	265	153	209

The discount rate used to estimate the annualized cost of investments incorporated in each scenario may also affect the results of the analysis. Specifically, the main set of results was obtained assuming a discount rate of 1% which reflects the current situation of low interest rates in the EU, but also the wider acknowledgement that it is not socially acceptable and economically viable to underestimate or ignore the effects of climate change on future generations, which is largely related to current decisions in the energy sector and the wider economy. In a more conservative approach, the comparative evaluation of the scenarios was repeated for a discount rate of 3%, requiring higher rates of return for the funds to invest in emission reduction measures. It should be noted that a high discount rate places a smaller value on the future, and results in a lower estimate of the social cost of carbon.

3. Results

3.1 Residential sector

In **Figure 9** the estimated reductions in GHG emissions (direct and indirect) in 2025 and 2030 due to the implementation of mitigation measures for the residential sector adopted in the various scenarios under consideration are presented. As the results show, in 2030 the total GHG emissions of the sector can be reduced between 44% and 58% compared to 2022, while even in 2025, where the time frames for the implementation of the measures are quite tight, the reductions can reach 10-19%. It is evident that a significant part of these reductions is related to the electrification of the buildings sector and the reduction of the carbon footprint of the power generation system.

Figure 10 presents in detail, the decomposition of the achieved GHG emissions reduction for each scenario into those resulting from the implementation of the scenario's measures and to those stemming from the "greening" of the central power generation system. Clearly, in the scenarios that incorporate energy upgrading of the existing building stock as well as the installation of photovoltaic systems, a significant part of the achieved reductions is attributed to the direct effects of the applied measures in reducing the energy demand, enhancing energy efficiency, and displacing fossil fuels. On the contrary, the scenarios focusing on the installation of heat pumps, most of the emission reductions are related to the decarbonization of the power generation sector.

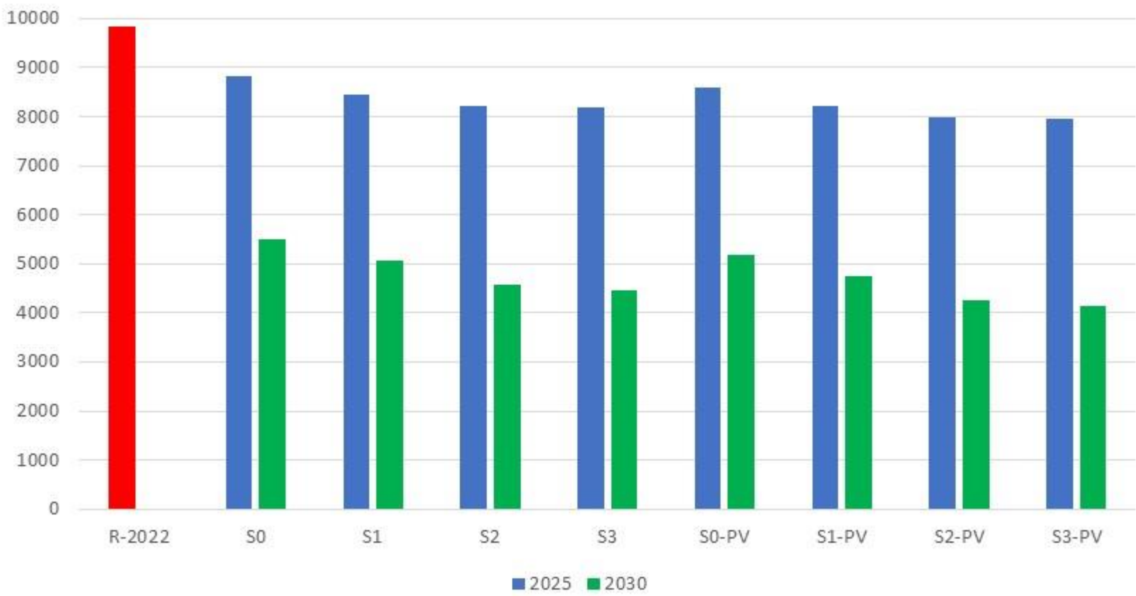
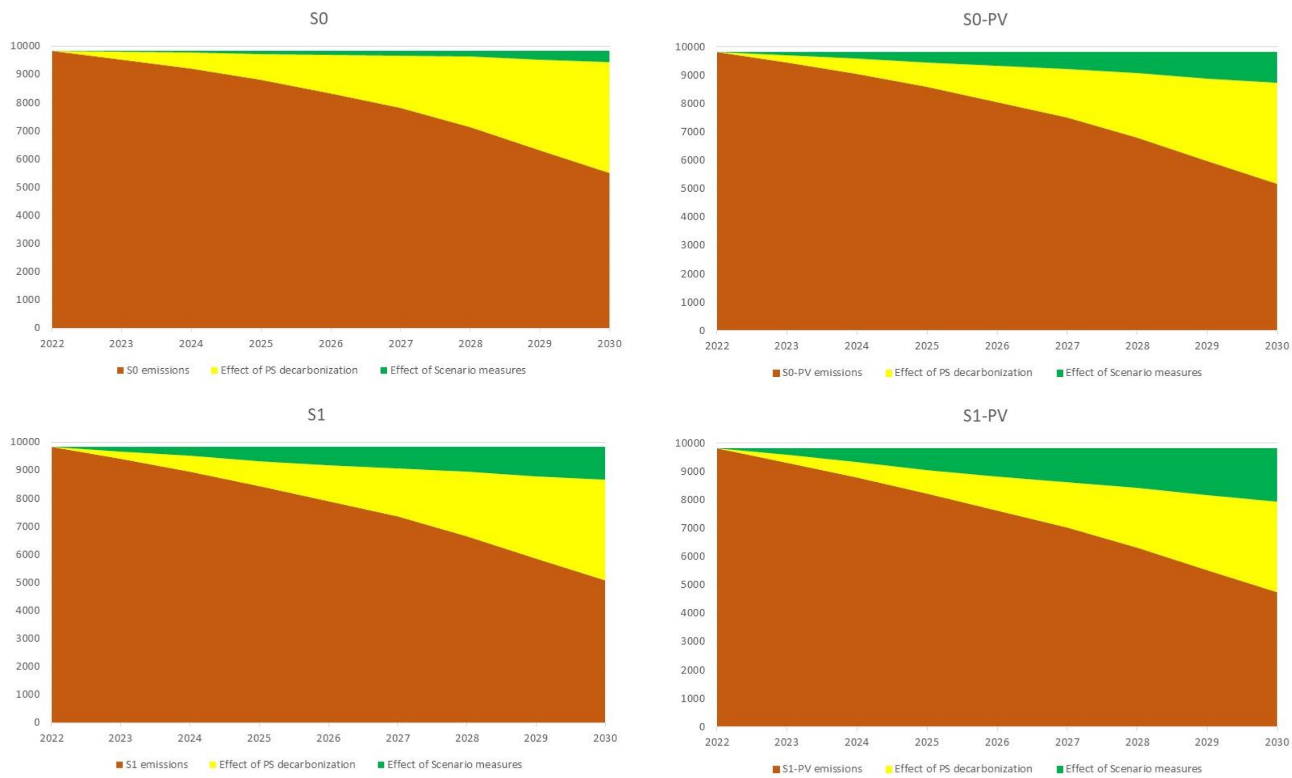


***Figure 9**: Evolution of the direct and indirect GHG emissions in the Greek residential sector, from 2022 to 2025 and 2030 in the various scenarios developed (in kt CO_2e).*



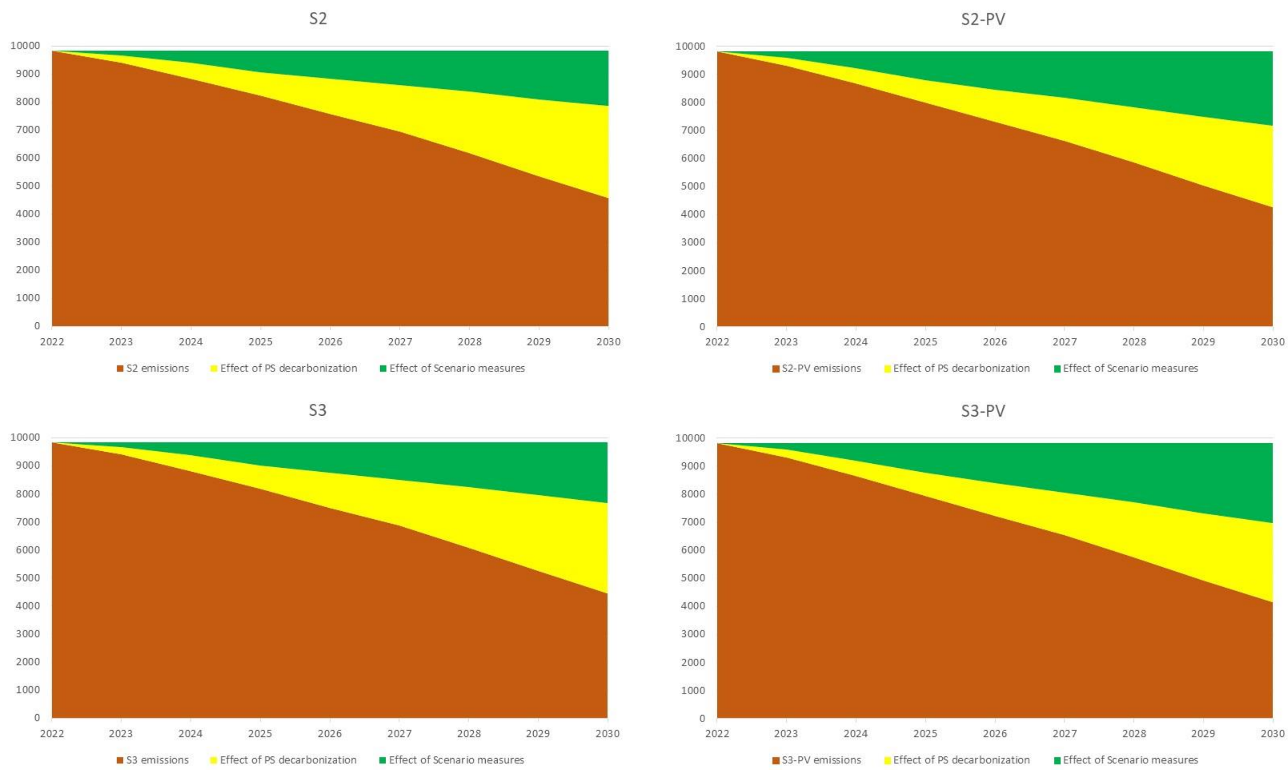
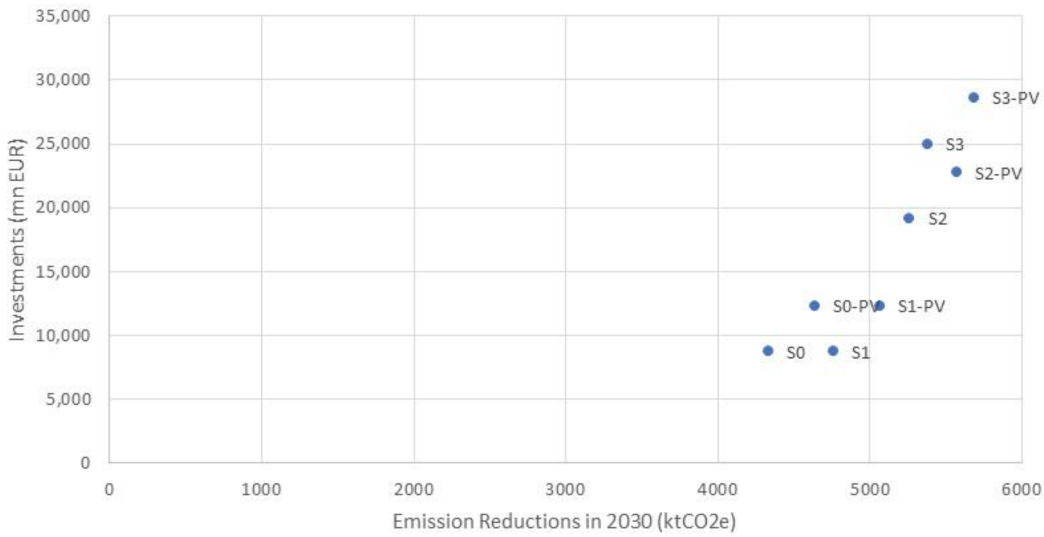
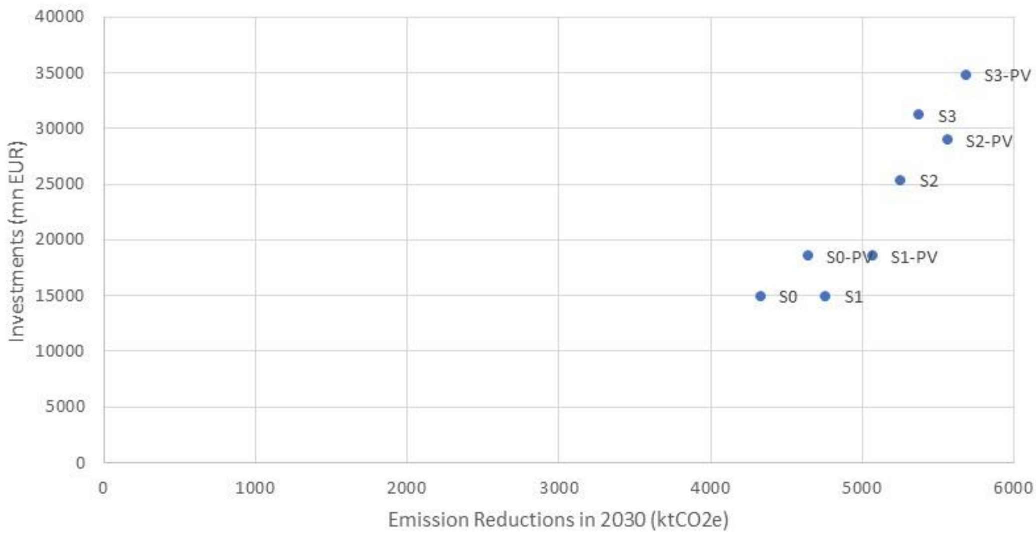


***Figure 10**. Direct (due to the implementation of mitigation measures in buildings) and indirect (due to the decarbonisation of the power sector) GHG emission reductions in the Greek residential sector and by scenario considered (in kt CO_2e).*

Reducing the carbon footprint of the building sector in Greece requires significant investments, which cumulatively in the period 2023-2030 range from 8.7 bn EUR (scenario S0) to 28.6 bn EUR (scenario S3-PV). **Figure 11a** presents, for all scenarios analyzed, the cumulative investments required during the period 2023-2030 in the Greek residential buildings in relation to the expected reductions in GHG emissions in 2030, the year that the intended penetrations of the planned interventions will have been achieved. Given that, as already mentioned, a significant part of the estimated GHG emissions reductions in the sector is related to the decarbonisation of the power system, **Figure 11b** also incorporates the investments required in the power generation sector, based on the relevant estimates of the Greek NECP and taking into account the share of total electricity consumption attributed to the residential buildings. In this case the cumulative investments of the period 2023-2030 range from 14.9 bn EUR (scenario S0) to 34.8 bn EUR (scenario S3-PV).



(a) Investments refer exclusively to measures implemented in residential buildings.



(b) Investments include both the expenditures required for implementing the measures considered in the residential buildings as well as part of the investments required for the decarbonisation of the power system.

Figure 11*: Cumulative investments per scenario in the period 2023-2030 (in mn EURs) and estimated GHG emission reductions in 2030 (in kt CO_2e/year).*

A comprehensive evaluation of the scenarios considered is given in **Figure 12**, where the estimated GHG emission reductions are presented in relation to the associated annual costs of these scenarios, which include both the annualized investment costs and the resulting energy expenditure savings. The analysis is presented for the year 2030 when the measures considered per scenario will have reached the intended penetration levels. The set of high energy prices and a discount rate of 1% have been adopted, while the main findings of the analysis could be summarized as follows:

- For four of the scenarios considered, namely S1-PV, S2-PV, S3, S3-PV the total estimated emission reductions are achieved with economic efficiency, i.e., the annual energy expenditure savings exceed the annualized energy investments. Scenarios S2-PV and S3-PV exhibit the best performance among the eight scenarios considered, with respect to both the total GHG emissions reductions achieved and their cost-effectiveness.
- The installation of photovoltaic systems in buildings seems to be of paramount importance in improving the performance of the scenarios as regards both their effectiveness in reducing GHG emissions and their cost-effectiveness. The main reason for this is that these scenarios utilize a technology, the investment cost of which has decreased significantly over the last two decades, in order to substitute the purchase of electricity from the grid, the prices of which are particularly high during the study period.
- Sufficiency measures improve the performance of the scenarios, increasing the total emission reduction potential by 10% at a very low cost. Therefore, this type of interventions should always be integrated into the decarbonization packages planned for the sector of buildings.
- The scenarios based mainly on the utilization of heat pumps present high costs due to the high electricity prices adopted for this analysis. On the contrary, the effectiveness and economic efficiency of the scenarios is significantly improved if the penetration of heat pumps is combined with energy upgrades of the building stock, which also enable the re-sizing of the heat pumps per dwelling and building.

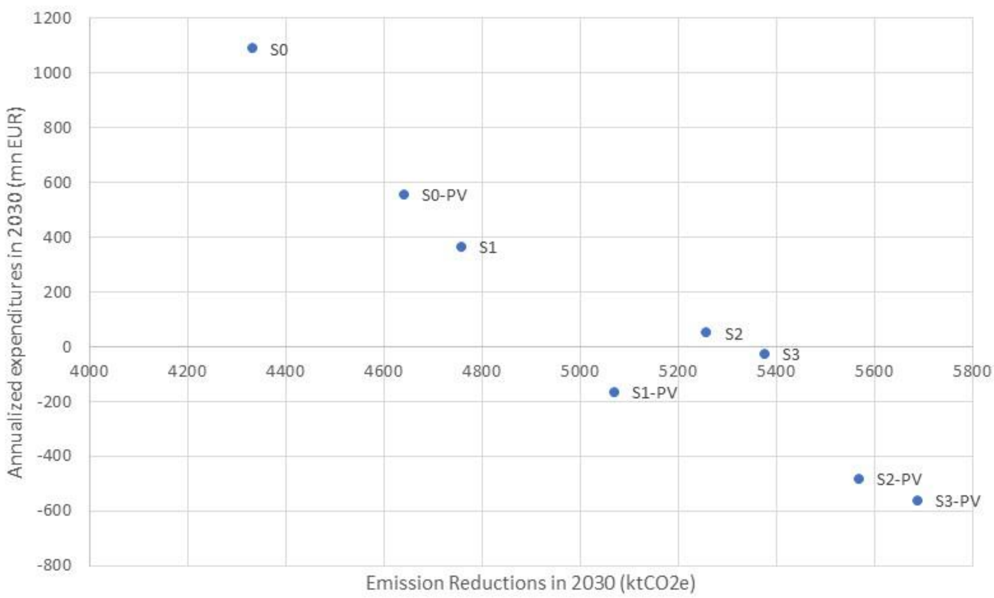


Figure 12: *Evaluation of the scenarios based on their annual costs, which include the annualized investments and the resulting energy savings, (in mn EURs) and the achieved emission reductions (in kt* CO_2e*/year) in the time horizon of 2030. This analysis was performed adopting the set of high energy prices and a discount rate of 1%.*

The qualitative features of the results do not differ significantly using the set of low energy values. The S2-PV and S3-PV scenarios still present the best performance and are the only ones that achieve total emission reductions with noticeable economic efficiency (**Figure 13**). However, the differences in the economic efficiency of the scenarios have been reduced compared to the high energy prices scenario (Figure 12) because of the lower electricity prices adopted in this parameter set. As a result, the utilization of heat pumps leads to a relatively improved performance of the scenarios favoring their very high penetration (mainly S0, S1 and S0-PV). The general picture does not change even if the analysis is repeated with the set of moderate energy prices considering the operation of the EU ETS2 in buildings and transport, through which fuel prices have increased relative to electricity prices (**Figure 14**). Scenarios S1-PV, S2-PV and S3-PV appear again to be feasible in terms of economic efficiency (i.e. negative annualized expenditure).

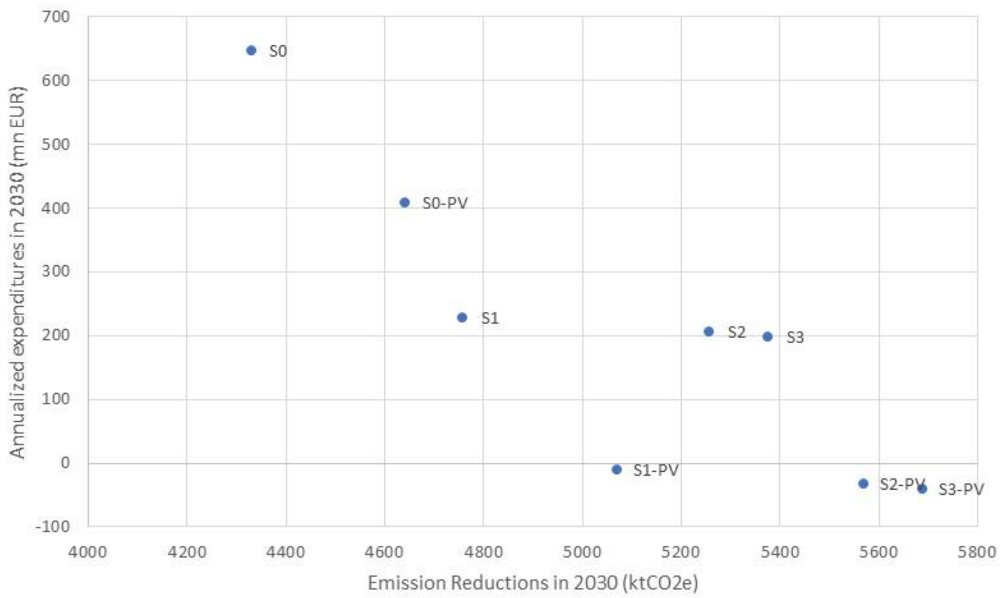


***Figure 13**: Evaluation of the scenarios based on their annual costs, which include the annualized investments and the resulting energy savings, (in mn EURs) and the achieved emission reductions (in kt CO_2e/year) in the time horizon of 2030. This analysis was performed adopting the set of low energy prices and a discount rate of 1%.*

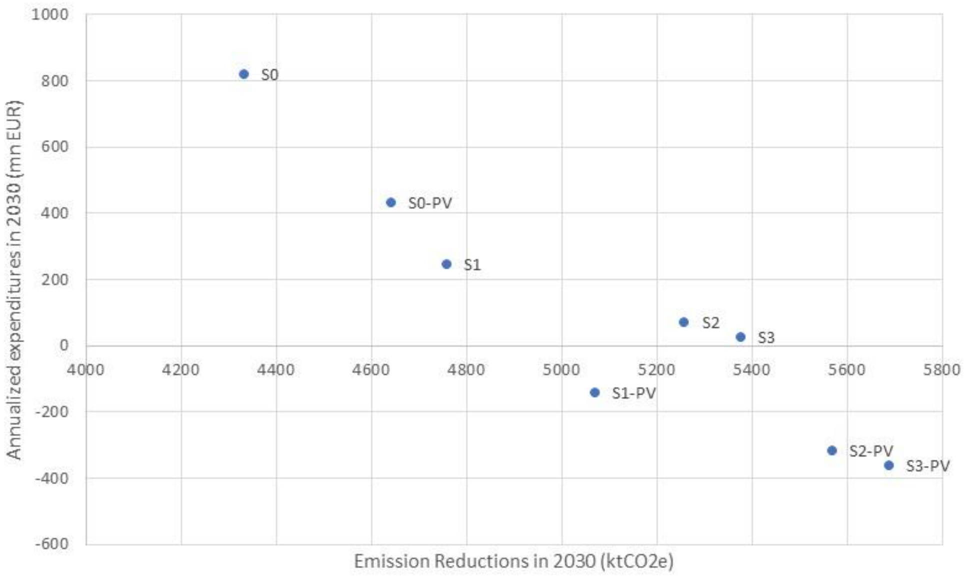


***Figure 14**: Evaluation of the scenarios based on their annual costs, which include the annualized investments and the resulting energy savings, (in mn EURs) and the achieved emission reductions (in kt CO_2e/year) in the time horizon of 2030. The analysis was performed adopting the set of moderate energy prices and the operation of ETS2 in buildings and transport as well as a discount rate of 1%.*

In **Figure 15** the effect of the discount rate is assessed by adopting a higher value of 3% compared to the parameter set of the base case. Although the main qualitative features of the performance of the scenarios are quite similar, the annualized expenditures in 2030 are increased under conditions of higher discount rates. Moreover, the order of the economic performance exhibits a relative shift with the scenarios integrating shallow energy renovations (i.e., S2 and S2-PV) becoming slightly more cost-efficient compared to the scenarios promoting the deep energy renovations (i.e., S3 and S3-PV respectively).

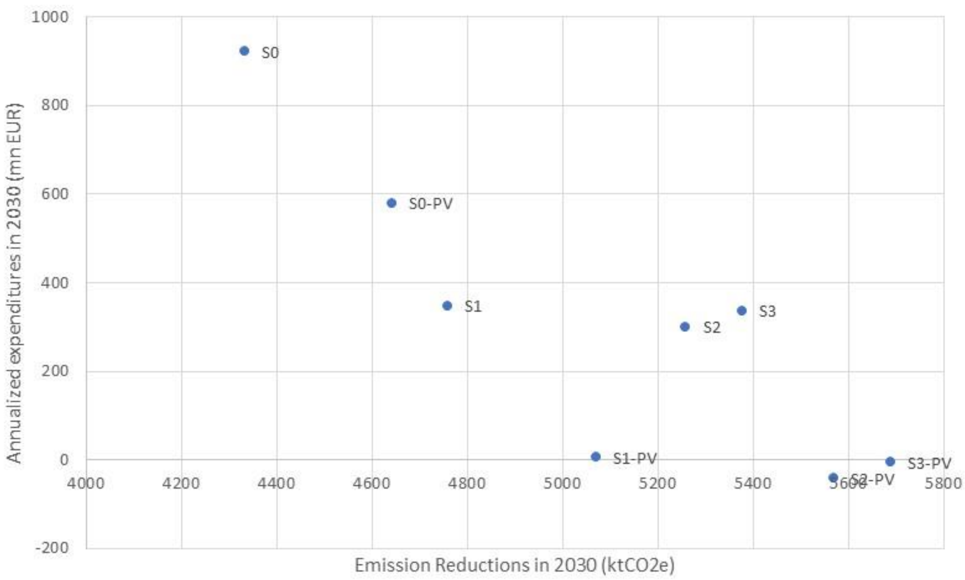


***Figure 15**: Evaluation of the scenarios based on their annual costs, which include the annualized investments and the resulting energy savings, (in mn EURs) and the achieved emission reductions (in kt CO_2e/year) in the time horizon of 2030. The analysis was performed adopting the set of moderate energy prices and the operation of ETS in buildings and transport as well as a discount rate of 3%.*

Finally, **Table 7** summarizes the variation of the unit abatement cost of reducing the GHG emissions in the residential sector in Greece throughout the 2023-2030 period considered in this analysis, for all the scenarios and the assumptions adopted in terms of energy prices and the discount rate.

***Table 7**: Cost of reducing GHG emissions in the Greek residential sector throughout the study period for all the considered scenarios & assumptions (in €/t CO_2e).*

	S0	S1	S2	S3	S0-PV	S1-PV	S2-PV	S3-PV
High energy prices and 1% discount rate								
2023	5797	243	243	243	666	-123	-123	-123
2024	6585	231	84	62	713	-130	-161	-167
2025	3817	118	-15	-35	575	-177	-207	-212
2026	4347	166	-5	-29	617	-157	-199	-207
2027	4388	236	16	-14	621	-128	-188	-198
2028	4172	276	22	-12	605	-113	-185	-197
2029	3096	299	28	-8	541	-94	-178	-192
2030	2804	313	26	-13	505	-89	-181	-197
Low energy prices and 1% discount rate								
2023	3548	169	169	169	504	-17	-17	-17
2024	4006	155	115	109	530	-26	-17	-17
2025	2289	79	57	53	426	-62	-45	-43
2026	2605	108	71	65	453	-48	-35	-34
2027	2627	151	91	82	455	-29	-23	-23
2028	2494	175	99	88	443	-19	-17	-18
2029	1848	188	105	92	397	-8	-12	-14
2030	1667	196	106	92	372	-6	-12	-14
Moderate energy prices with ETS in buildings and transport and 1% discount rate								
2023	4450	163	163	163	537	-97	-97	-97
2024	5045	150	65	52	572	-105	-114	-116
2025	2891	59	-10	-21	453	-146	-149	-150
2026	3295	96	2	-12	487	-130	-140	-143
2027	3325	150	22	4	489	-106	-128	-132
2028	3157	181	30	9	476	-94	-124	-130
2029	2339	200	36	14	425	-79	-117	-124
2030	2110	210	36	12	394	-75	-118	-126
Moderate energy prices with ETS in buildings and transport and 3% discount rate								
2023	4991	250	250	250	702	-19	-19	-19
2024	5640	237	171	177	739	-28	-21	-9
2025	3253	135	92	103	601	-75	-58	-42
2026	3696	176	110	120	639	-56	-45	-28
2027	3727	236	136	143	641	-30	-28	-13
2028	3541	270	147	153	626	-15	-22	-7
2029	2627	287	153	157	562	-1	-15	-1
2030	2376	298	154	157	528	3	-16	-2

In summary, our analysis emphasizes measures which support building renovations instead of mostly improving efficiency of appliances which is the focus of the draft NECP. Furthermore, it finds that combining such measures with the installation of PV to cover domestic electricity needs (either small rooftop PV or larger PV via energy communities) leads to optimal results in terms of reducing both the carbon footprint and energy bills of the households. Specifically, installing PV on top of shallow (S2-PV) or deep (S3-PV) renovations, heat pumps and sufficiency measures leads to net profits for the period 2023-2030 as indicated by the negative values of annualized expenditures, which include not only the investment costs but also the economic benefits for the households. These values range from -€6 Mn up to -€561 Mn per year in 2030, depending on the values of the parameters examined in the sensitivity analysis we conducted (energy prices, discount rates).

Since the mix of measures we propose is different than that of the NECP, differences in the total investment costs are also expected. Although it is difficult to make precise comparisons due to the lack of knowledge of the specific assumptions employed in the NECP, we note that, according to the latter, the total expenditures dedicated to the residential sector (renovations and energy appliances) for the period 2023-2030 is 29.2Bn (€6.3 Bn for renovations and €22.9 Bn for appliances). On the other hand, the total investment costs for our scenarios S0, S1, S2 and S3 for the same period are € 8.7 Bn, € 8.8 Bn, € 19.1 Bn and € 25 Bn, respectively. Moreover, the total investment costs for the two scenarios which emerged from this analysis as the most economically efficient (S2-PV and S3-PV), range from €22.7-28.6 Bn, lower or at the same order of magnitude with that of the draft NECP. However, almost 50% in S2-PV or even more in S3-PV of the investments in these scenarios concern renovations of old dwellings. The annualized expenditures that were calculated for these scenarios, have been found to be negative under a wide range of parameter values (figures 12-15). In addition, both scenarios (S2-PV and S3-PV) which emphasize building renovation in conjunction with PV, have negative costs per tonne of CO2 emissions reductions they achieve for every year during the study period (Table 7), thus both scenarios were shown to be simultaneously beneficial for the climate and the national economy. Hence, their implementation through the development of appropriate financial instruments and incentives should be pursued.

3.2 Passenger transport

In total, 6 GHG emissions reduction measures were examined for passengers' transport in Greece, of which 5 are included in the sufficiency category and one (electrification of private cars) is included in the efficiency category. The GHG emissions reduction potential estimated for each measure in line with assumptions and the penetration rates discussed in Table 1, is presented in Figure 16. The maximum potential is presented for 2030 when the maximum penetration rate considered, is achieved.

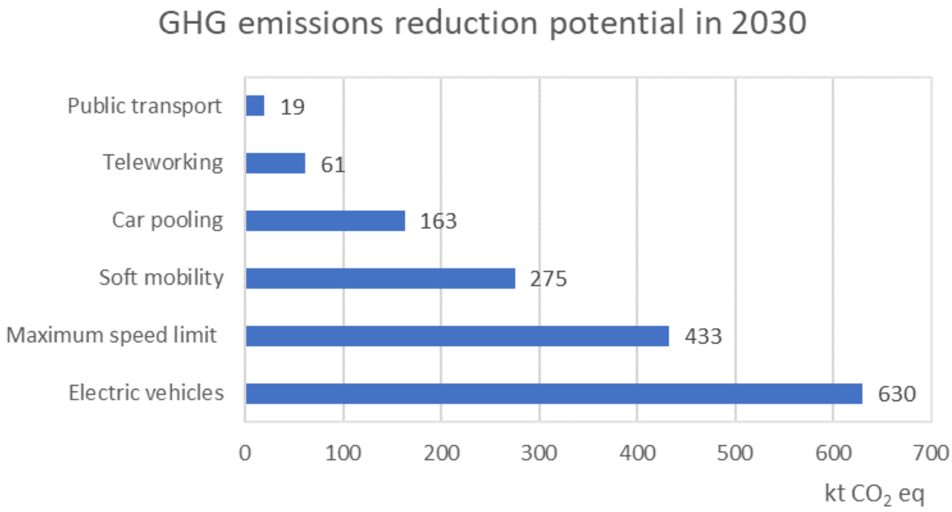


Figure 16. *GHG emissions reduction potential (in kt CO_2e/year) of the measures considered for passenger transport in 2030. Interactions between measures that may affect the estimated potential are not considered.*

The electrification of passenger cars presents the highest reduction potential, reaching about 630 kt CO_2e. This potential accounts for about 7% of the emissions in 2022 (9,074 kt CO_2e from passenger cars, motorcycles, busses, metro and tram) and includes the effect of the decarbonization of the electricity generation sector, as estimated by the current NECP (2019), which is significantly more conservative in terms of the penetration of renewables in the electricity sector compared to the revised versions examined in 2023 (61% vs 79-80% RES-e shares). Excluding this effect, the potential is reduced to about 480 kt CO_2e stemming mainly from the displacement of fossil fuels in passengers' transport.

Of the sufficiency measures considered, the reduction of the maximum speed limit on motorways exhibits the highest potential reaching 433 kt CO_2e (that is about 5% of emissions in 2022), followed by soft mobility measures (275 kt CO_2e, i.e., 3% of emissions in 2022), carpooling (163 kt CO_2e) and teleworking (61 kt CO_2e).

The results of the two scenarios developed, by means of GHG emissions for 2025 and 2030, are presented in Figure 17. It should be kept in mind that:

- Scenario T1 only considers the electrification of the vehicle fleet, as defined in the current NECP, that is a share of 18,5% for BEV by 2030 (Table 4).
- Scenario T2 assumes that both the electrification of the vehicle fleet and the whole set of sufficiency measures included in Table 4 are implemented. Compared to T1 scenario, the number of electric vehicles introduced is the same but with lower mileage per vehicle.

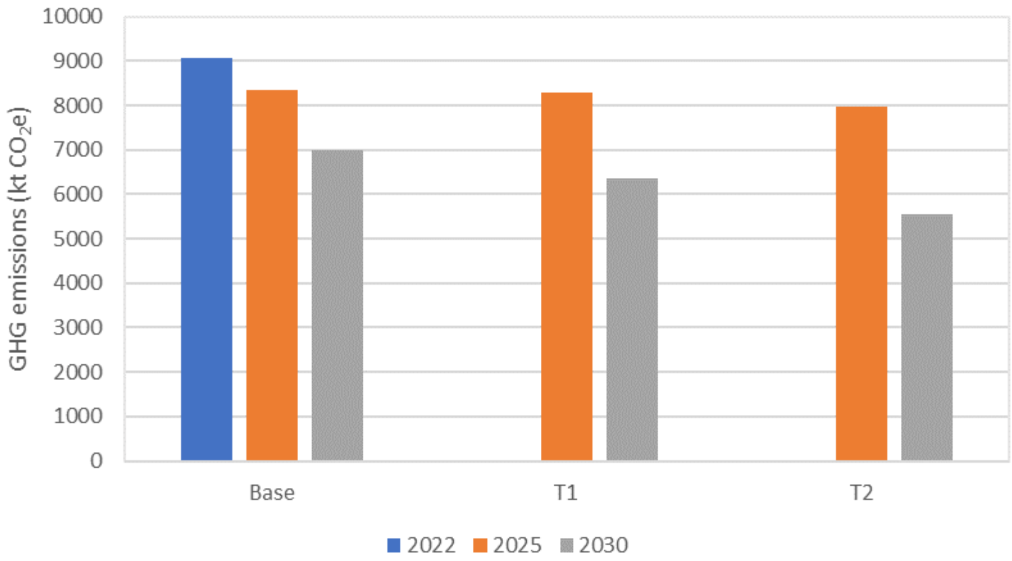


Figure 17: *GHG emissions (in kt CO_2e/year) in 2025 and 2030 for the scenarios developed for passengers' transport.*

In the T1 scenario, GHG emissions in 2030 are estimated at 6354 kt CO_2e, that is a decrease of 30% compared to 2022 and an additional decrease of 7% compared to the base scenario. The estimated decrease is related to:

- the improved fuel economy of "conventional" passenger cars, resulting in reduced energy consumption for the same transportation activity.
- the electrification of passenger cars stock (about 896,000 electric vehicles in 2030 or about 654,000 electric vehicles additional to those included in base scenario), resulting in reduced fossil fuel consumption (diesel oil and gasoline).
- the decarbonization of the electricity generation sector enables lower emissions during vehicle charging.

In the T2 scenario, GHG emissions in 2030 (5542 kt CO_2e) decreased by 39% compared to 2022. This is an additional decrease of 16% compared to the base scenario. The additional (compared to T1 scenario) emissions decrease estimated for this scenario is clearly attributed to the penetration of the sufficiency measures considered that reduced transportation activity of passenger cars and the associated energy consumption.

Scenarios results are summarized in **Table 8** based on the emissions reductions achieved, the annualized investment cost needed and the corresponding economic benefits (in terms of reduced energy expenditures). All results presented in Table 5 refer to 2030, when the maximum penetration rate assumed is achieved.

- Reducing GHG emissions in passengers transport requires significant investments, which cumulatively in the period 2023-2030 are estimated at 22,900 mn EUR for the T1 scenario and at 22,928 mn EUR for the T2 scenario.

Investments required in the power generation sector are not included in the above-mentioned figures.

- The sufficiency measures contribute significantly to the reduction of energy expenditures. Considering the set of high prices, energy expenditures are reduced by 360 mn EURs in the T1 scenario (compared to 2022 and excluding benefits generated within the context of the base scenario) and by 1070 mn EURs in the T2 scenario. Energy expenditures reduction is almost three times higher when sufficiency measures are implemented. Corresponding results with the set of medium and low prices show a reduction in the expected benefits but on a qualitative basis there are no changes.
- The expected reduction of energy expenditure estimated for the scenarios examined is lower than the investment cost needed (in terms of annualized investment cost). For the T1 scenario, energy expenditures reduction account for 12-15% of the annualized investment cost (depending on energy prices assumptions), while for the T2 scenario they account for about 33-45% of the annualized investment cost.

Table 8: *Parameters for the economic assessment of the scenarios examined under different assumptions regarding energy prices and discount rate.*

	T1 scenario	T2 scenario
GHG emissions reduction (kt CO_2e)		
Including decarbonization of power sector	630	1442
Excluding decarbonization of power sector	479	1301
Investment cost (mn EUR)		
Total	22900	22928
Annualized cost, 1% discount rate	2418	2446
Annualized cost, 3% discount rate	2685	2713
Energy expenditures reduction (mn EUR)		
High prices	360	1070
Medium prices	286	851
Low prices	296	810

The analysis for passenger transport up to 2030 showed that the electrification of vehicles fleet will contribute significantly to the reduction of GHG emissions and this contribution is expected to increase following the decarbonization of the electricity generation sector. The planned ban of conventional passenger cars motor drives running on fossil fuels by 2035 at EU and national levels, is expected to boost sales of electric cars. However, the high cost of electric cars needs to be addressed given the limited available income of households, but also the need to reduce emissions across all activities at national level.

To this end, this analysis showed that for an almost negligible additional investment cost, the implementation of sufficiency measures for passenger transport such as the reduction of the maximum speed limit, soft mobility, carpooling and tele-working, achieve 812-822 ktCO2/year of additional GHG emissions reductions and €514-710

Mn/year of additional energy expenditure reductions for the households compared to only emphasizing electromobility as is the case with the NECP.

4. Concluding remarks and policy implications

Over 60% of the energy consumption in the Residential sector is used for heating and cooling. If, energy for hot water is added, this percentage increases to over 75%. It is thus important to focus on policies which simultaneously reduce energy losses and increase energy efficiency in heating/cooling systems. The first purpose of reducing heat losses is primarily achieved through renovation of buildings, whereas energy efficiency can be significantly enhanced by increasing the installation rate of heat pumps.

Measures for upgrading buildings are already in place in Greece but their aim is focused on improving insulation and their scope, till now, is proscribed by the limited available funding for subsidies and by bureaucratic drag. Additional measures in place provide incentives for the installation of PV on roofs and for the replacement of some operating appliances (refrigerators and A/C) with new ones with better efficiency. As these existing measures are not coordinated, they do not take full advantage of synergies. It is therefore important to try to identify how the results of the analysis presented above can provide guidance to policy makers who, at this critical period of upheavals in the energy markets and uncertain economic prospects worldwide, are called upon to address energy poverty and to ameliorate household energy expenditures in an inflationary environment.

Furthermore, the results of this analysis can provide very timely guidance to policy makers who are called now to finalize the revised NECP. The draft NECP has just (7 November 2023) been submitted to the EC unfortunately without public consultation. It has been announced by the Ministry of Environment and Energy that, a version of the final draft which will take into consideration the recommendations of the European Commission -, will be submitted for public consultation before its final version is submitted by June 2024.

The policy recommendations stemming from the results of this analysis are the following:

1. Call for the obligatory replacement of fossil fuel-based heating systems (oil and gas) with heat pumps. The results of this analysis clearly show the added value of implementing such measures in conjunction with the renovation of the existing building stock, which has the added advantage of resizing the heat pumps to meet the reduced energy needs of the renovated structures, while also increasing the use of electricity to cover the heating/cooling needs. This will in turn further contribute to the overall GHG emissions reduction due to the substitution of fossil fuels with electricity, the carbon

footprint of which will continue to decrease as a result of the continuous increase of renewables in the electricity mix to 79% of the gross electricity consumption and to 44% of the total demand by 2030 according to the submitted draft NECP.

2. Measures should be implemented to encourage changes in consumer choices towards sufficiency which can still ensure adequate living comfort and thus to avoid a rebound effect. The effectiveness of such measures is demonstrated by the notable reductions in GHG emissions between scenarios S0 and S1 at virtually no cost. Such soft measures to encourage prudent energy use should aim, besides heating/cooling, also at the rational usage of all electric devices, which account for the rest 25-35% of household energy consumption. Gradually and in the long-run structural measures towards energy sufficiency should also be considered.

3. Comparison of the results for the S2 (shallow renovation) scenario with the ones for the S3 scenario (deep renovation at almost double the cost per unit but applied to 80% of the units for shallow renovation per year) shows that the achieved GHG emissions reduction difference between the two from heating/cooling is very small. Consequently, as the lifetime of building renovations is long, at first glance that would favor prioritization of deep renovation measures albeit resulting in a smaller number (65000/yr for the same expenditure as that for 100000/yr shallow ones). On the other hand, the larger expenditure needed for deep renovation would make it less affordable for lower income households while at the same time the larger number of subsidy recipients for shallow renovations might make them more attractive to implement. Thus, it is recommended that deep renovation should be preferred in designing renovation support measures, but shallow is also acceptable as is a combination of the two. In renovating, the non-negligible contribution of insulating films on windows (of ca 3% in heating needs) at minimal cost should be noted and included in the design of renovation programs.

4. As fossil fuels will still contribute approximately 18% of electricity production in 2030, measures to encourage PV installations to cover the electricity needs in residential buildings, already on-going but at a small scale and with implementation problems n, especially as part of renovation are particularly meaningful, since such systems were found to reduce the overall emissions in an efficient way in all scenarios. Therefore, it is recommended to support the increase in the installation rate of small PV systems for self-consumption purposes, possibly in combination with battery storage systems to reduce the required grid space. The installation of larger systems through energy communities attempting to cover collectively the energy needs of a number of households is expected to be also environmentally and economically effective and should be an alternative for households aiming to generate their own electricity.

5. In this analysis, programs such as the one recently instituted to encourage replacement of appliances with newer more efficient ones were not considered. Instead, normal replacement rates were adopted which will clearly lead to better overall efficiency. This choice was based on the smaller percentage of energy demand from household appliances compared to heating/cooling and hot water, and on the rather high cost/benefit ratio of this measure. The funds allocated to this replacement program could be put to better use in supporting heat pump utilization, as well as increasing the installation rates for solar water heaters and PV systems.

6. Programs considered in this analysis that involve 100000 renovations/yr and the installation of heat pumps to half the building stock as well as over 2GW of PV require substantial investments. As mentioned earlier, the total expenditures, public and private, might reach over 28bn EUR for the period 2023-2030. The larger part of this amount is expected to come from private funds. To incentivize such private expenditure, a crucial argument is provided by this analysis which finds that the installation cost is recovered over the lifetime of the renovation/installation by the reduction in energy costs. Under high or moderate energy prices and small discount rates, all renovations with PV installations have a negative annualized expenditure which means that the investment cost will be recovered well before its lifetime. Even at high discount rates, the annualized cost hovers around zero for all scenarios with PV, that is the investment is at no cost over its lifetime. Therefore, it is recommended for the State to provide financial incentives (subsidies, low interest loans) which will aid citizens in implementing the aforementioned measures in conjunction with communication campaigns highlighting the favorable economics of investing in renovations, heat pumps and PV systems.

7. In the transport sector, besides the obvious benefits of high penetration of BEVs, it is important to underline the contribution of the sufficiency measures that comprise the difference between scenarios T1 and T2. These combined measures (speed limit reduction, soft mobility, rail use, carpooling) result in a substantial reduction that exceeds in total that of the BEV penetration till 2030. One of them, the reasonable reduction of the speed limits (by 10-15km/hr) already proposed and applied elsewhere[9] will result in a reduction of the carbon footprint equal to all the other soft measures combined and approximately equal to 2/3 of that from the increase in BEV penetration. Therefore, it is highly recommended to implement the speed limit reduction measure especially as it requires no expenditure by households and has led to spectacular results in previous energy crises.

Of interest is a comparison of the measures examined here and proposed for implementation with those of the latest (November 2023) revised NECP.

[9]https://bit.ly/3SZOXc1

The major differences in the residential buildings sector are seen to be, (a) the increase of the yearly renovation rate in the present scenarios, (b) the earlier installation of heat pumps, (c) the smaller reliance on appliance replacement and (d) the soft measures for sufficiency. We found that combining such measures with the installation of PV to cover domestic electricity needs (either small rooftop PV or larger PV via energy communities) leads to optimal results in terms of reducing both the carbon footprint and energy bills of the households.

Specifically, installing PV on top of shallow (S2-PV) or deep (S3-PV) renovations, heat pumps and sufficiency measures leads to net profits for the period 2023-2030 as indicated by the negative values of annualized expenditures, which include not only the investment costs but also the economic benefits for the households. These values range from -€6 Mn up to -€561 Mn per year in 2030, depending on the values of the parameters examined in the sensitivity analysis we conducted (energy prices, discount rates).

Since the mix of measures we propose is different than that of the NECP, differences in the total investment costs are also expected. Although it is difficult to make precise comparisons due to the lack of knowledge of the specific assumptions employed in the NECP, we note that, according to the latter, the total expenditures dedicated to the residential sector (renovations and energy appliances) for the period 2023-2030 is 29.2Bn (€6.3 Bn for renovations and €22.9 Bn for appliances). On the other hand, the total investment costs for our scenarios S0, S1, S2 and S3 for the same period are € 8.7 Bn, € 8.8 Bn, € 19.1 Bn and € 25 Bn, respectively. Moreover, the total investment costs for the two scenarios which emerged from this analysis as the most economically efficient (S2-PV and S3-PV), range from €22.7-28.6 Bn, lower or at the same order of magnitude with that of the draft NECP. However, almost 50% in S2-PV or even more in S3-PV of the investments in these scenarios concern renovations of old dwellings. The annualized expenditures that were calculated for these scenarios, have been found to be negative under a wide range of parameter values (figures 12-15). In addition, both scenarios (S2-PV and S3-PV) which emphasize building renovation in conjunction with PV, have negative costs per tonne of CO2 emissions reductions they achieve for every year during the study period (Table 7), thus both scenarios were shown to be simultaneously beneficial for the climate and the national economy. Hence, their implementation through the development of appropriate financial instruments and incentives should be pursued.

In the passenger transport sector, again the major difference with respect to the NECP is the inclusion of soft but effective measures which are mentioned but not quantified in the NECP. As regards penetration of BEVS, the NECP includes a higher penetration not differing notably from that of this analysis in the 2025-2030 period. The soft measures examined here on the other hand, such as the reduction of the maximum speed limit, soft mobility, carpooling and tele-working, achieve for an almost negligible additional investment cost 812-822 KtCO2/year of additional GHG emissions reductions and €514-710 Mn/year of additional energy expenditure reductions for the households, and should be considered as "no-regret" and appropriate policies to implement them should be developed.

The results then of this analysis would be of high relevance in the public consultation of the draft Greek NECP, when it is finally put out for comments as promised before adoption by June of 2024.

The analysis of measures to reduce energy use and GHG emissions presented in this report has been carried out to be used in the public debate on policies to meet not only the intermediate targets in 2030 but also those for 2040 for emission reductions on the way to full net zero in 2050. Its focus was on policies that affect the household budget, namely energy and transport expenditures and thus of high political impact.

The policies considered are to be applied immediately, that is in the period to 2030 which is a horizon in line with the four-year term of a government and the period needed for implementation. It is also in line with the revised NECPs that have already been commented on by the EC toward the June 2024 deadline for their adoption by Member States. In addition, it covers the next term of the EC and the EU multi-year budget.

All of the policies and measures (PaMs) analyzed are already in operation or have been under consideration in Greece and in other countries. What is of added value in this analysis is the ability to examine alternative scopes of such PaMs including in particular sufficiency measures and do so in a transparent but robust bottoms-up methodology with minimal computation resources needs and easily reproducible for use in other countries or regions. It is hoped that it would be of help especially to civil society organizations that are interested in social aspects of energy impacts as well as to other political organizations in proposing enhancement to or alternative policies to those put forth so far by the government.