IAM COMPACT

Expanding Integrated Assessment Modelling:
Comprehensive and Comprehensible Science
for Sustainable, Co-Created Climate Action

D5.2 - Climate action social & distributional impacts

WP5 – Expanding – Resilient, inclusive, and sustainable recovery and development

28/02/2024

Funded by
the European Union

www.iam-compact.eu

Disclaimer

Copyright Message

Grant Agreement Number	101056306		**Acronym**	IAM COMPACT
Full Title	Expanding Integrated Assessment Modelling: Comprehensive and Comprehensible Science for Sustainable, Co-Created Climate Action			
Topic	HORIZON-CL5-2021-D1-01-04			
Funding scheme	HORIZON EUROPE, RIA – Research and Innovation Action			
Start Date	September 2022		**Duration**	36 Months
Project URL	https://www.IAM COMPACT.eu			
EU Project Advisor	Andreas Palialexis			
Project Coordinator	National Technical University of Athens – NTUA			
Deliverable	D5.2 – Climate action social & distributional impacts			
Work Package	WP5 – Expanding – Resilient, inclusive, and sustainable recovery and development			
Date of Delivery	**Contractual**	29/02/2024	**Actual**	28/02/2024
Nature	Report		**Dissemination Level**	Public
Lead Beneficiary	Basque Centre for Climate Change			
Responsible Author	Xaquín García-Muros		**Email**	Xaquin.garcia@bc3research.org
	BC3		**Phone**	N/A
Contributors	Xaquín García-Murosa, Eva Alonso-Epelde, Alejandro Rodríguez-Zúñiga, Mikel González-Eguino [BC3]; Kostas Fragkiadakis, Faidra Filipidou, Panagiotis Fragkos, Theofano Fotiou [E3M]; Eleni Kanellou, George Konstantopoulos, Alexandros Nikas, Haris Doukas [NTUA]			
Reviewer(s)	Eleftheria Zisarou [E3M]; Natasha Frilingou [NTUA]; Wolfgang Obergassel [WI]			
Keywords	Distributional impacts; inequality; equity; energy poverty			

EC Summary Requirements

1. Changes with respect to the DoA

No changes with respect to the work described in the DoA.

2. Dissemination and uptake

The results of this deliverable will be disseminated through IAM COMPACT's website, and uploaded onto Zenodo, while parts have been shared with the wider scientific community through publication in peer-reviewed journals. The report will also act as a guidance on the modelling of distributional impacts of key policies and can inform discussions with stakeholders within the second cycle of our Policy Response Mechanism.

3. Short summary of results (<250 words)

The main objective of this report consists of the synthesis and description of the first distributional analysis performed in the IAM COMPACT project. Therefore, in this deliverable we show two different examples on distributional analysis with two different methodologies, approaches and focus regions, which represent a good example of the type of analysis that can be performed in IAM COMPACT. The first analysis explores the distributional consequences of a key policy at EU level, using a microeconomic model which includes a large database on European households. On the other side, the second analysis offer an overview of the distributional impacts on vulnerable households of different climate policy paths in Greece. For doing so, GEM-E3-FIT is expanded to represent ten household income classes in EU Member States, to consistently capture the potential distributional impacts of ambitious energy and climate policies for Greece until 2050. Moreover, each of the analyses has focused on one key socioeconomic dimension: the impacts on gender of a European policy in the first analysis and the consequences of climate policies on energy poverty (focusing on low-income households) in Greece in the second analysis. Finally, the deliverable also includes the description of a tool, called MEDUSA, that will allow the integration of information from other IAMs used in IAM COMPACT to perform distributional and social analyses throughout the duration of the project. Initially developed for the Spanish economy, MEDUSA is planned to be made available to explore the social implications of the entire EU during the project.

4. Evidence of accomplishment

This report.

Section 2 is part of a paper to be presented at the EGU 2024 as well as to be submitted to Elsevier's Energy Policy (or a similar policy-oriented journal) for a possible publication.

Section 3 is part of the paper: Fragkos, P., Kanellou, E., Konstantopoulos, G., Nikas, A., Fragkiadakis, K., Filipidou, F., Fotiou, T., & Doukas, H. (2023). Energy Poverty and Just Transformation in Greece. In R. Bardazzi & M. G. Pazienza (Eds.), Vulnerable Households in the Energy Transition (pp. 235–267). Springer International Publishing. https://doi.org/10.1007/978-3-031-35684-1_10

Section 4 describes a model that is open source and available at: https://bc3lc.github.io/medusa/

Preface

IAM COMPACT supports the assessment of global climate goals, progress, and feasibility space, and the design of the next round of Nationally Determined Contributions (NDCs) and policy planning beyond 2030 for major emitters and non-high-income countries. It uses a diverse ensemble of models, tools, and insights from social and political sciences and operations research, integrating bodies of knowledge to co-create the research process and enhance transparency, robustness, and policy relevance. It explores the role of structural changes in major emitting sectors and of political, behaviour, and social aspects in mitigation, quantifies factors promoting or hindering climate neutrality, and accounts for extreme scenarios, to deliver a range of global and national pathways that are environmentally effective, viable, feasible, and desirable. In doing so, it fully accounts for COVID-19 impacts and recovery strategies and aligns climate action with broader sustainability goals, while developing technical capacity and promoting ownership in non-high-income countries.

NTUA – National Technical University of Athens	EL	
Aalto – Aalto Korkeakoulusaatio SR	FI	
AAU – Aalborg Universitet	DK	
BC3 – Asociacion BC3 Basque Centre for Climate Change – Klima Aldaketa Ikergai	ES	
Bruegel – Bruegel AISBL	BE	
CARTIF – Fundacion CARTIF	ES	
CICERO – Cicero Senter for Klimaforskning Stiftelse	NO	
E3M – E3-Modelling AE	EL	
KTH – Kungliga Tekniska Hoegskolan	SE	
POLIMI – Politecnico di Milano	IT	
UPRC – University of Piraeus Research Center	EL	
UVa – Universidad De Valladolid	ES	
WI – Wuppertal Institut fur Klima, Umwelt, Energie GGMBH	DE	
IIMA – Indian Institute of Management	IN	
THU – Tsinghua University	CN	
USMF – University System of Maryland	US	
AAiT – Addis Ababa University	ET	
KEI – International Civic Organisation Kyiv Economics Institute	UA	
RUSL – Raja Rata University of Sri Lanka	LK	
TUM – Technical University of Mombasa	KE	
UNIGE – Université de Genève	CH	
Imperial – Imperial College of Science, Technology and Medicine	UK	

Funded by
the European Union

Executive Summary

The main objective of this report consists of the synthesis and description of the first distributional analysis performed in IAM COMPACT. Therefore, in this deliverable, we show two different examples on distributional analysis with two different methodologies, approaches, and focus regions, which represent a good example of the type of analysis that can be performed in the context of the project. The first analysis explores the distributional consequences of the Energy Taxation Directive, a key policy at the EU level, using a microeconomic model that includes a large database on European households. The second analysis offers an overview of the distributional impacts on vulnerable households of different climate policy paths in Greece. In this context, GEM-E3-FIT has been expanded to represent ten household income classes in EU Member States, to consistently capture the potential distributional impacts of ambitious energy and climate policies for Greece until 2050. Moreover, each of the analyses has focused on one key socioeconomic dimension: the first on the impacts on gender of a European policy, and the second on the consequences of climate policies on energy poverty (with a focus on low-income households) in Greece. Finally, the deliverable also includes the description of a tool, called MEDUSA, that will allow the integration of information from other Integrated Assessment Models (IAMs) used in IAM COMPACT to perform distributional and social analyses throughout the duration of the project. Initially developed for the Spanish economy, MEDUSA is planned to be made available to explore the social implications of the entire EU during the project.

The success of the targets established in the European Green Deal depends on the correct and efficient design of ambitious policies that utilise all available instruments, including energy and environmental taxation. In the "Fit for 55" package, the EC proposed a deep reform of the Energy Taxation Directive (New ETD) to update the current taxation and align it with current environmental goals. However, due to the war in Ukraine, the energy crisis, and the risk of regressive effects, the proposal of the EC was stalled. Therefore, the first analysis on this deliverable seeks to provide new evidence from a microsimulation model developed to assess the direct, overnight distributional impacts of the proposed new ETD reform on households. Our aim is to explore whether the proposed EU-level "polluter pays" instruments can be designed to achieve progressive distributional impacts, to identify policy options that ensure they strengthen social justice without undermining it, and thereby remove social barriers for the energy transition. Moreover, we explore a dimension often underrepresented in distributional analyses, namely gender. Our results indicate that, with the correct design from the outset, environmental tax reforms can be progressive without increasing current inequalities between and within Member States of the EU, including those related to gender.

Low-income population groups often face high energy poverty risks. This phenomenon can be exacerbated through the implementation of ambitious environmental policies to achieve the energy transition—said policies, such as the application of additional taxes on energy products, may lead to regressive social and distributional impacts on low-income household, thus increasing the risk of energy poverty. Therefore, the second analysis in this deliverable focuses on Greece and combines a qualitative analysis of the EU and Greek policy context and strategic framework for energy poverty as well as related poverty alleviation measures with a state-of-the-art model-based assessment of the equity and distributional impacts of the net-zero transition in the country and ways to alleviate the regressive impacts of climate policies. We use the GEM-E3-FIT general equilibrium model, expanded to represent ten income classes differentiated by income sources, saving rates, and consumption patterns. The new modelling capabilities of GEM-E3-FIT are applied to quantify the distributional impacts of ambitious emission reduction targets and at the same time explore their effects on energy-related expenditure and energy poverty by income class in Greece. The country's transition to climate neutrality increases modestly the income inequality across income classes, with low-income households facing the most negative effects. However, using carbon tax revenues as lump-sum transfers to support household income and as reduced social security contributions has the potential to boost employment and scale down income inequality in Greece.

These two analyses offer a good overview of the type of distributional analysis that is and will be performed in

the context of the IAM COMPACT project. However, they use different tools and approaches that can be challenging to integrate into other IAMs used and developed during the project. Therefore, the deliverable also includes the description of MEDUSA, which allows the integration of information from other IAMs used in IAM COMPACT to perform distributional and social analyses throughout the duration of the project. While IAMs are fundamental tools for exploring the dynamics of different climate and energy paths at the macro- and sectoral levels, micro-simulation models for distributional analysis have the advantage of providing more heterogeneous results. This helps in more robustly identifying the socio-economic and distributional impacts of the policies to be implemented, making it possible to identify the people who will be most affected by such policies and to implement compensatory measures to make the policy fairer and avoid social rejection. Thus, the combination of both methods (IAMs and microsimulation models) through a platform like MEDUSA provides a powerful tool for generating valuable results for decision-making.

Funded by
the European Union

Contents

EC Summary Requirements ii
Executive Summary iv
Contents vi
1 Introduction 8
2 The socioeconomic impacts of the Energy Taxation Directive 11
2.1 Methodology for analysing the distributional consequences of the ETD in the EU 12
2.1.1 Microsimulation 12
2.1.2 Data 13
2.2 Scenarios of the new ETD and its price impacts 14
2.2.1 New Energy Taxation Directive Scenarios. 14
1.2.2 Price impacts of the new ETD proposal 16
2.3 Results: socioeconomic impacts of the new ETD. 20
2.3.1 Vertical analysis 20
2.3.2 The gender dimension on the distributional impacts of the new ETD 24
2.3.3 Other horizontal impacts 28
2.3.4 The capacity of the revenues to compensate welfare impacts. 29
2.4 Conclusions about the social implications of the new ETD. 30
3 Energy poverty & just transformation in Greece. 31
3.1 Strategic framework for energy poverty in Greece 31
3.1.1 EU policy context 31
3.1.2 National policy context 33
3.2 Measuring the problem 33
3.2.1 The diversity of indicators to identify and measure energy poverty 33
3.2.2 Measuring energy poverty in Greece 35
3.3 Energy poverty alleviation measures in Greece 36
3.4 Implications of the European Green Deal on energy poverty and equity 41
3.4.1 Inequality and energy poverty indicators 42
3.4.2 Modelling income inequality and energy poverty with GEM-E3-FIT 45
3.4.3 Scenario design 48
3.4.4 Results on socio-economic and distributional effects 48
3.4.5 Results on energy poverty 52
3.5 Conclusions 55
4 MEDUSA - Modelling Equity and DistribUtional impacts for Socioeconomic Analysis 57
4.1 The household microsimulation model 57
4.2 The R package 59
4.3 Conclusions and further research 70
5 References 71
Annex A: Supplementary material of microsimulation for ETD analysis 76

Funded by
the European Union

Table of Figures

Figure 1. Welfare impacts by income groups at EU level 21
Figure 2. Welfare impacts by national income groups 22
Figure 3. Energy expenditure patter in by EU-Deciles....23
Figure 4. Welfare impacts according to the gender of the reference person and Feminisation degree of the Household....24
Figure 5. Welfare impact according to different socioeconomic characteristics....26
Figure 6. Welfare impact according to different socioeconomic characteristics....27
Figure 7. Welfare impact according to different socioeconomic characteristics....28
Figure 8. Welfare impact of ETD 3 with revenue Recycling schemes 29
Figure 9. Share of energy expenditure in income by income decile in Greece 44
Figure 10. GEM-E3-FIT model structure 46
Figure 11. Composition of Greek labour value added by skill in the REF scenario....50
Figure 12. Evolution of the Gini coefficient in Greece in the REF scenario....51
Figure 13. Changes in the composition of value added by skill in Greece in DECARB compared to REF....52
Figure 14. Energy expenditure Indicator 1 by income decile in Greece in 2020. 53
Figure 15. Energy expenditure Indicators in Greece for each income decile in 2050 in DECARB scenario....54
Figure 16. Change in total income per decile group in DECARB_EQ scenario relative to REF over 2030-2050 ...55

Table of Tables

Table 1. Numerical models, data and methods to explore Climate action social & distributional impacts.... 8
Table 2. Expenditure classification of energy goods used in the micro model by COICOP category 13
Table 3. Minimum nominal tax rates of main energy products 15
Table 4. Change in final prices by energy products and country in ETD_1 16
Table 5. Change in final prices by energy products and country in ETD_2 17
Table 6. Change in final prices by energy products and country in ETD_3 18
Table 7. Total revenues by country and ETD scenario. 19
Table 8. Energy poverty alleviation measures in Greece 36
Table 9. Indicators to measure income inequality 43
Table 10. Scenario description....48

1 Introduction

Addressing the major challenges of the 21st century, such as climate change, will require complex and ambitious policies that promote social justice combined with ambitious climate action. To do so, it is necessary to design efficient policies that do not exacerbate existing inequalities, such as income or gender inequality. In this sense, it is essential to carry out impact analysis from a holistic perspective that evaluates the economy, energy, land, and water systems in an integrated manner before implementing such policies. For doing so, it is also necessary to develop methodologies and tools that can capture the different socioeconomic dynamic on the society.

As it is recognised in the last IPCC report, modelling still struggles to bring together detailed physical and economic climate impacts and mitigation, with limited representation of distributional dynamics (IPCC, 2022). Hence, inequality and vulnerable groups are severely underrepresented in modelling (van Soest et al., 2019). This underrepresentation is especially pronounced in Integrated Assessment Models (IAMs), as these models, which include information on several countries, regions, sectors, and economic agents, very often lack information on categories of households or socioeconomic groups and are therefore unable to report on the socioeconomic and distributional consequences of the climate transition. This gap in modelling is also due to the lack of large databases and information that can be easily accessed and applied in economic models. Therefore, IAM COMPACT tries to reduce this gap by using state-of-the-art methodologies to generate more detailed evidence of the extent of transition impacts on different household typologies using large databases and integrating them with IAMs. Microeconomic models (MS) and databases are an appropriate tool for assessing micro-economic effects and distributional impacts of policies and for showing the impact of climate protection measures on consumers, however partial analysis often limits the overall perspective, particularly from a macro and multiregional standpoint. On the other hand, IAMs provides an economy and technology-wide analysis that is not captured with MS. Therefore, the main advantage of linking these approaches is that environmental protection can be analysed from different perspectives, in particular, equity and efficiency.

The novelty of IAM COMPACT lies in the interdisciplinary combination of several micro data sources from different countries, the analysis of these data, and the integration of large data for households and individual information in macro models. The list of numerical models, data and methods used is presented in Table 1.

Table 1. Numerical models, data and methods to explore Climate action social & distributional impacts.

	Method-Data	Type	Distinguishing feature in IAM COMPACT
Micro Models and data	Microdata	Micro-economic data from household surveys	The household surveys provide information about households' final consumption on goods and services and information on socioeconomic characteristics.
	Microsimulation	Microsimulation models based on large data from household surveys	Distributional effects (horizontal and vertical) of climate mitigation policies and possible compensatory scenarios.
Macro Models and data	IAMs	Integrated Assessments Models	IAMs presents an exhaustive description of the productive process and of the resource-use balance of the international economy.
	CGE	Multi-regional, multi-sector CGE model	Analyse the economic impacts of public policies, both economic, energy, environmental or fiscal.

Funded by
the European Union

Integrated Methods	IAMs-MS Methods	Multi-household, multi-regional, multi-sector, IAMs	Analyse the socioeconomic and distributional impacts of public policies that directly affect households, both economic, energy, environmental or fiscal at multiregional level.

Hence, through these methods, that include households' databases, IAM COMPACT performs granular analyses that has rarely been performed on IAMs literature. These analyses allow to explore vulnerable dimension considering important social and cultural characteristics beyond income groups that might be impacted differently such as race/ethnicity, family size, gender, geographical location (rural/urban), or level of education. Among these socioeconomic characteristics, in this first approach IAM COMPACT focuses in two of them, which can be especially relevant when exploring vulnerability: gender and energy poverty. Gender issues play a relevant role in just transition and are a key element of energy and climate justice (Feenstra & Özerol, 2021). Prior research identifies differential vulnerability of women to mitigation policies (Markkanen & Anger-Kraavi, 2019) and differences in support for climate mitigation policies. Policies that reduce economic inequality can also reduce gender inequalities, especially if female-headed households are over-represented in the low-income groups. Likewise, the energy poverty context is playing a relevant role on the energy and political debate, since climate policies can have a greater impact on those that are already vulnerable. Energy poverty, understood as the inability of a household to achieve a socially and materially necessary level of household energy services (Bouzarovski & Petrova, 2015), is currently at the centre of public debate (Baker et al., 2018) (Dobbins et al., 2019), especially due the current energy crisis. Moreover, the cost associated with climate action may disproportionately affect households at risk of energy poverty in the short term.

The main objective of this report consists of the synthesis and description of the first distributional analysis performed on IAM COMPACT. Therefore, in this deliverable we show two different examples on distributional analysis with two different methodologies, approaches and focus regions, which represent a good example of the previously mentioned methodologies and the type of analysis that can be performed with them. The first analysis explores the distributional consequences of a key policy at EU level, the Energy Taxation Directive, using a microeconomic model which includes a large database on European households. On the other side, the second analysis offers an overview of the distributional and the impact on vulnerable households of different climate and policy paths in Greece. For doing so, GEM-E3-FIT is expanded to represent ten household income classes in EU Member States, to consistently capture the potential distributional impacts of ambitious energy and climate policies for Greece until 2050. Moreover, each of the analyses has focused on one of the previously mentioned socioeconomic dimensions: the impacts on gender of a European policy in the first analysis and the consequences of climate policies on energy poverty in Greece in the second analysis.

These two analyses offer a good overview of the type of distributional analysis that is and will be performed in the environment of the IAM COMPACT project. However, they use different tools and approaches that can be challenging to integrate into other IAMs used and developed during the project. Therefore, the deliverable also includes the description of a tool, called MEDUSA, that will allow the integration of information from other IAMs used in the project to perform distributional and social analyses throughout the duration of the project. Initially developed for the Spanish economy, MEDUSA is planned to be made available to explore the social implications of the entire EU during the project.

While IAMs are fundamental tools for exploring the dynamics of different climate and energy paths at the macro and sectoral levels, micro-simulation models for distributional analysis have the advantage of providing more heterogeneous results. This helps in more robustly identifying the socio-economic and distributional impacts of the policies to be implemented (Bourguignon & Spadaro, 2006). These models make it possible to identify

Funded by
the European Union

population groups who would be most affected by policies and to implement compensatory measures to make the policy fairer and avoid social rejection. Thus, the combination of IAMs and microsimulation models through a platform like MEDUSA provides a powerful tool for generating valuable results for decision-making.

MEDUSA is an R package that allows the development of distributional analyses in isolation or in connection with other models such as IAMs. Its extensive database allows for highly disaggregated results, considering numerous socio-economic and demographic characteristics of households, such as income level, place of residence, type of family or the degree of feminisation of the household. At the moment, the prototype works for Spain, but in the short term the idea is to extend it to all EU countries. However, the package could be extended to all countries that are able to provide the raw data required by the model.

This deliverable is structure as follows. Section 2 presents and describe the methodology and modelling developed to analyse the social impact of the direct incidence of these policies on European households. Section 3 focusses on Greece and combines a qualitative analysis of the EU and Greek policy context and strategic framework for energy poverty as well as related poverty alleviation measures with a state-of-the-art model-based assessment of the equity and distributional impacts of the net-zero transition in the country. Finally, Section 4 describes MEDUSA, a method that allows developing distributional analyses based on a microsimulation model and is designed to work in isolation or in connection with other models such as IAMs.

Funded by
the European Union

2 The socioeconomic impacts of the Energy Taxation Directive[1]

The European Green Deal sets out a vision for making Europe a climate-neutral economy by 2050 and has established a target for a net reduction of emissions of at least 55% by 2030 compared to 1990 levels (EC, 2018, 2020, European Commission, 2019). To achieve this goal, the European Commission is currently implementing the "Fit for 55" package, a policy package that contains many different legislative proposals to revise and reinforce the entire EU climate and energy framework to 2030. One important instrument of this new package is the use of carbon pricing and, in particular, the reform of the Energy Taxation Directive (ETD).

The current ETD (2003/96/EC) does not guarantee that the most carbon-intensive energy goods are taxed the highest in many European countries (EC, 2021). Therefore, the new ETD proposal introduces a new structure of tax rates based on the energy content and environmental performance of the fuels and electricity. It also broadens the taxable base by including more products in the scope and by removing some of the current exemptions and reductions. In this way, the new system will ensure that the most polluting fuels are taxed the highest.

The public acceptance of carbon and energy taxation has been very low in many Member States (MS) among citizens. In fact, although this reform was planned to be already introduced is has been delayed due to the energy crisis, and with further negotiations expected in 2024 during the Belgium presidency. However, there is little evidence of the distributional and social impacts of the ETD reform and its design. This will be critical to avoid potential regressive impacts and to design compensations mechanism.

The lack of studies on the direct distributional impacts of the revision of the new ETD is particularly pronounced concerning possible gender impacts. Although it is well-established that gender plays a relevant role in the social impacts of climate policies (Alber, 2009; Allwood, 2014, 2020), there is still no evidence on the role gender can play in the impacts of climate policies in general (Alonso-Epelde et al 2024) and in the new ETD in particular. This is important as the European Parliament has urged to collect gender-disaggregated data when assessing of climate policies (European Parliament, 2012a). The European Parliament's report on women and climate change (European Parliament, 2012b) has also called on the Commission and the European Council to mainstream gender in all phases of climate policy analysis to ensure that climate action does not increase gender inequalities.

This analysis provides evidence from a microsimulation model developed to assess the direct, overnight distributional impacts of the proposed ETD reform on households. It explores whether the proposed tax reform can be designed to achieve progressive distributional impacts, and to identify policy options to ensure they strengthen and do not undermine social justice. The rich representation of households that we provided allows us to develop vertical distributional analysis, analysing the impact according to the different income levels, as well horizontal distributional analysis, i.e., including different socioeconomic characteristics of the European households and therefore also to incorporate gender impact of the examined policies.

This section is structured as follow. Section 2.1 presents and describe the methodology and data used and section 2.2 describes the scenarios simulated. Section 2.3 describes the results and key findings in relation to the impact

[1] This section is based on data from Eurostat, Households Budget Survey (HBS) 2010 and 2015. The responsibility for all conclusions drawn from the data lies entirely with the authors.

of the new ETD, and explores the capacity of extra revenues to compensate households. Finally, Section 2.4 concludes.

2.1 Methodology for analysing the distributional consequences of the ETD in the EU

In this section, the methodology and data used in the analysis is presented. We have developed a micro-simulation model that allows us to simulate the distributional and social impacts at a household level. This model uses the microdata from the Household Budget Surveys for 2015 provided by EUROSTAT for each country, a database that gathers information from more than 200.000 households.

2.1.1 Microsimulation

The microsimulation model used in this study follows a similar approach to Tomás et al (2023). The model simulates the expenditure change according to the consumption categories (COICOP), multiplying the changes in prices induced by the ETD reform to current levels of expenditure on the different products. Thus, the model reflects the direct impacts of the scenarios (described in section 2.2.1) before assuming any changes in behaviour related to the new prices[2]. The results derived from the model are presented in relative impact (%) on income[3]. The monetary impact can be described as:

$$\Delta e_h^s = \frac{\sum_c e_{c,h} \Delta p_c^s - \sum_c e_{c,h}}{w_h} \quad \text{(E.1)}$$

where Δe_h^s represents the impact in monetary units for each household and scenario, $\mathbf{e_{c,h}}$ refers to the total expenditure on each consumption category, c, consumed by each of the household, h, in the baseline scenario; Δp_c^s is the increase in prices by consumption category and scenario obtained with the price analysis; and w refers to the weight of each household. The relative impact, $\Delta \varepsilon_h^s$, shows the same additional costs but in relative terms (in percentage), compared to the initial household expenditure, and it is calculated as:

$$\Delta\Delta\varepsilon_h^s = \frac{\sum_c e_{c,h} \Delta p_c^s - \sum_c e_{c,h}}{\sum_c e_{c,h}} \, x100 \text{ (E.2)}$$

Table 2 offers an overview of the different energy products included in the model and also provides the categories of each of them. In supplementary material, more information about the data is included.

[2] Our microsimulation model does not capture the behavioural change of households, i.e., it does not reflect the reaction of different types of households to expected changes in energy prices. In this sense, the results on energy bills only reflect the change in relative prices applied to household consumption structures before the reform. A "behavioural" impact study would require the use of a more sophisticated tool that would capture direct consumer reactions (through price elasticities of demand for energy goods) and induced reactions (through cross-elasticities and income elasticities). However, these effects are known to be small in the short and medium term, as households do not easily change their energy consumption behaviour, as the scientific literature have shown that the price elasticities of energy consumption are usually very low (see Labandeira et al., 2017).

[3] Equivalent expenditure is used instead of income as it is considered a better proxy for permanent household income since it fluctuates less in the long run (Goodman & Oldfield, 2004). The equivalent spending is calculated based on household spending relativized by the modified OECD equivalence scale, thus considering the economies of scale generated in households based on their size. The modified OECD scale values 1 for the reference person in the household, 0.5 for other people aged 14 or over, and 0.3 for other people under 14 years of age.

Funded by the European Union

Table 2. Expenditure classification of energy goods used in the micro model by COICOP category

Variable	HBS COICOP Code(s)	Expenditures
Total	**COICOP 00**	**Total expenditure**
Total energy	**COICOP** 045	Electricity, gas and other fuels
Electricity	**COICOP 0451**	**Electricity from all sources**
Heating	**04521 + 04522 + 0453 + 0454**	**Gas and other fuels for heating**
Natural gas LPG Liquid fuels	04521 04522 0453	Natural gas and town gas LPG Liquid fuels for domestic heating
Solid fuels	0454 = 04541 + 04549	Solid fuels for domestic heating
Coal Other solid fuels	04541 04549	Coal Other solid fuels that are not coal
Fuels	**COICOP 0722 = 07221 + 07222**	**Fuels for personal transport equipment**
Diesel Petrol	07221 07222	Diesel fuel for transport Petrol/gasoline for transport

Finally, and in order to capture the gender implications, we use two different approaches: the gender of the reference person of the household and the feminisation degree of the household. Although the HBS already includes the gender of the reference person, the second indicator is calculated using complementary information which includes the gender of each of the household members. Following Osorio et al., 2022, we calculate the percentage of household members who are women over 14 years[4] and then we divide the households into 5 groups based on the share of women: FD1 from 0 to 20% (lower feminisation degree), FD2 from 20% to 40%, FD3 from 40% to 60%, from 60% to 80% and from 80% to100% (higher feminisation degree).

2.1.2 Data

This study has used two primary sets of information. First, the information on the household expenditure on energy goods. And second the tax structure for the different energy goods included in the ETD reform that allows us to calculate its effect on final consumer prices and, therefore, on energy expenditures.

The microdata source for HBS is the latest harmonised data wave of Eurostat[5]. The most recent information available covers all EU countries for 2015[6] (except Malta, Portugal, and Slovenia, for which data from 2010 HBS

[4] We establish 14 years old as the age at which we consider members of the family to play a greater role in household decisions and to be more independent in transportation.

[5] https://ec.europa.eu/eurostat/documents/54431/1966394/HBS_EU_QualityReport_2015.pdf/72d7e310-c415-7806-93cc-e3bc7a49b596

[6] Whereas most countries conducted their HBS in 2010 (first wave) and 2015 (second wave), others carried it out in different years. For the first wave, DE (Germany), LT (Lithuania) and MT (Malta) in 2008, CY (Cyprus) and SE (Sweden) in 2009 and FI (Finland) in 2012; and, for the second wave, SE (Sweden) in 2012, DE (Germany) in 2013, BE (Belgium) and HR (Croatia) in 2014, FI (Finland) and LT (Lithuania) in 2016 and FR (France) in 2017. In these cases, Eurostat adjusted the monetary data to 2010 and 2015 respectively using price coefficients.

Funded by
the European Union

will be used)[7]. The database for this study gathers very detailed expenditures of more than 200.000 European households. The data on household consumption expenditure includes information of goods and services in monetary units (for all items) following the classification of individual consumption by purpose (COICOP). It also includes different socio-demographic variables of households and individuals.

The data used to simulate the price impacts has been obtained from different official sources, all prices are for the 2020 year[8]. Information about petrol and diesel for transportation and gas oil for heating is from Weekly Oil Bulletin (European Commission, 2023) and from natural gas for heating and electricity from Eurostat (Eurostat, 2023b, 2023a). Information about coal comes from DG TAXUD (European Commission, 2023). More details about the HBS and data can be found in the supplementary material (Annex A).

2.2 Scenarios of the new ETD and its price impacts

This section describes the different scenarios that we have developed to analyse the new ETD in the various member states. It also elaborates on the price impacts that these different scenarios can entail and identifies the main key driving forces that explain the results of our analysis.

2.2.1 New Energy Taxation Directive Scenarios.

The new ETD has revised and update the tax rates on energy goods (European Commission, 2021). The proposal introduces a new tax rates structure based on the energy content and environmental performance of the fossil fuels and electricity. It also broadens the taxable base by including more products in the scope and by removing some of the current exemptions and reductions. In this way, the new system will ensure that the most polluting energy products are taxed the highest.

Table 3 offers a comparative between the ETD 2003 tax rates and the new proposal from the European Commission by energy product. The current proposal not only increases tax rates on fossil fuels, but also establishes other measures that favour the electrification of the economy. The EC has therefore proposed that electricity should be the least taxed energy product. Several MS currently tax electricity well above the current minimum ETD rates, so the new ETD could have a large impact on electricity prices. Lowering the electricity tax rate may also mean a large reduction in Member State revenues, which will introduce the debate of how to finance this cut in the government budget.

Based the different policy implementations that the final ETD may have, we have developed the following three different scenarios:

- **Scenario ETD 1**: Increasing tax rates of fossil fuels and maintaining current taxation of electricity. In this scenario we assume that Member States will increase the minimum tax rates of fossil fuels to the new ETD proposal, and they will maintain current tax rates in electricity.

[7] Since the HBSs are the property of the national statistical institutes of European countries, authorization from them is necessary for data usage. We have obtained authorization from all Member States except Austria. Consequently, the study was unable to analyze the impacts of the new ETD in the case of Austria

[8] Due to the COVID crisis, 2020 could not be an ideal year for analysing some policies. However, this is not the case for energy prices, as 2020 is the last year before the energy price crisis started. Therefore, the 2020 energy prices should be more similar to those that the Member States (MS) will experience in the future. Moreover, these prices do not include the several measures that the Member States have temporarily implemented during the energy crisis, which could affect the ETD analysis.

Funded by
the European Union

- **Scenario ETD 2**: Increasing tax rates of fossil fuels and lowering taxation of electricity. Following the new ranking taxation criteria, electricity should be taxed as the lowest energy product. In this scenario we assume that Member States will increase minimum tax rates on fossil fuels while reducing tax rates in electricity to the lowest of the ranking. In this scenario we assume that in case the revenues from the ETD reform are negative due to the reduction of the electricity tax rate, they will be financed through the State budget, i.e., we do not consider further tax increments to compensate for the loss of revenues.
- **Scenario ETD 3**: Increasing tax rates of fossil fuels and lowering taxation of electricity to the minimum of the ranking with net impact in Member States budget. In Member States that has net negative revenues from the ETD reform (Scenario ETD 2), we assume that Member States will additionally increase the taxation of other fossil energy products in proportion to current energy consumption to compensate for the lower revenues from the cut in electricity tax rates.

These scenarios allow us to disaggregate the socioeconomic impacts of the new ETD, as we will explore first the direct impact of the fossil fuel taxation (ETD_1), second the lowering of the electricity taxation (ETD_2), and finally the possible impact of a neutral tax reform for those with negative revenues due the electricity taxation reduction (ETD_3).

Table 3. Minimum nominal tax rates of main energy products

Energy good	End use	ETD 2003/96/EC	New ETD
	€/1000 litres		
Gasoline	Transport	359	398.6
Diesel	Transport	330	344.4
Gas Oil	Heating	21	34.8
	€/GJ		
Natural gas	Heating	0.3	0.6
	€/MWh		
Electricity	Lighting/Heating	1	0.54
	€/GJ		
Coal	Heating	0.3	0.9

*During transitional period[9]

The ETD reform also envisages the possibility of introducing exemptions on heating energy products for very low income and vulnerable households. Therefore, in each scenario we introduce this exemption on the increase of tax rates in heating energy products. To introduce the exemptions, we define vulnerable households as those whose income (we used expenditure as a proxy for living income) is below the poverty threshold. The poverty threshold is defined by EUROSTAT as 60% of the median income in each country[10].

Finally, the ETD_3 scenario is complemented with scenarios in which the new revenues are recycled through lump-sum transfers to compensate households. Two revenue recycling scenarios are considered: i) an equal lump

[9] We use transitional tax rates because as mentioned in the ETD revision proposal, there are some fossil fuels based but less harmful and still have some potential to contribute to decarbonisation in the short medium term. This is the case of natural gas and means that we use 0,6 €/GJ as nominal tax rate instead of 0,9 €/GJ. After the transitional period this rate will increase to the full reference rate.

[10] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:At-risk-of-poverty_rate

Funded by
the European Union

sum for all households, whereby all households will receive the same transfer; and ii) an equal lump sum for the poorest 50% of households in each country, this second income recycling scenario attempts to explore whether income support for low-income households can ensure a fair and more progressive reform.

1.2.2 Price impacts of the new ETD proposal

The application of minimum tax rates on energy products under the new ETD proposal will lead to an increase in the final prices of fossil energy products. This subsection presents the price impact on private transport fuels, heating products and electricity prices under the different scenarios.

Table 4 shows the price change in the scenario ETD_1 due to the application of new minimum tax rates to fossil fuels. Although the impact is limited in most countries, there are some MS that will be affected. For example, Hungary would have to increase final prices in petrol, diesel, natural gas, and coal by 3.9%, 11.8%, 8.8% and 14.5% respectively. Poland would have to increase the final prices in diesel, natural gas and coal by 10%, 6.3% and 12.5% respectively (see Table 4). The highest price increases would result from coal due to its higher carbon intensity. Also, Germany would have to increase the price of coal by 33.9% and Luxembourg by 21.6%. However, the distributional impact of higher coal prices would be very marginal in many Member States, as coal consumption in households is very low, especially in West EU.

As can be seen in table 4, six countries are currently taxing above the minimum tax rates of the new ETD proposal so there will be no price changes in these countries: Austria, Denmark, Finland, France, Ireland, and Sweden. Eleven countries will have to increase taxes in diesel to meet the new ETD.

Table 4. Change in final prices by energy products and country in ETD_1

Member State	Petrol %	Diesel %	Gas oil %	Electricity %	Natural gas %	Coal %
Austria	0.0	0.0	0.0	0.0	0.0	0.0
Belgium	0.0	0.0	3.8	0.0	2.9	11.6
Bulgaria	0.0	8.8	0.0	0.0	7.0	13.2
Cyprus	0.0	0.0	0.0	0.0	0.0	13.2
Czechia	0.0	1.1	0.0	0.0	4.7	14.6
Germany	0.0	0.0	0.0	0.0	0.0	33.9
Denmark	0.0	0.0	0.0	0.0	0.0	0.0
Estonia	0.0	2.7	0.0	0.0	0.0	0.0
Spain	0.0	2.0	0.0	0.0	0.0	5.2
Finland	0.0	0.0	0.0	0.0	0.0	0.0
France	0.0	0.0	0.0	0.0	0.0	0.0
Greece	0.0	0.0	0.0	0.0	2.3	13.4
Croatia	0.0	0.0	0.0	0.0	7.0	13.3
Hungary	3.9	11.8	0.0	0.0	8.8	14.5
Ireland	0.0	0.0	0.0	0.0	0.0	0.0
Italy	0.0	0.0	0.0	0.0	0.0	9.2
Lithuania	0.0	3.0	3.3	0.0	8.1	13.4
Luxembourg	0.0	0.0	6.2	0.0	3.0	21.6
Latvia	0.0	0.0	0.0	0.0	2.1	2.8
Malta	0.0	0.0	0.0	0.0	0.0	13.4
Netherlands	0.0	0.0	0.0	0.0	0.0	9.0
Poland	0.0	10.0	0.0	0.0	6.3	12.5
Portugal	0.0	6.3	0.0	0.0	0.0	0.0

Funded by
the European Union

Romania	0.0	7.2	0.0	0.0	8.0	12.9
Sweden	0.0	0.0	0.0	0.0	0.0	0.0
Slovenia	0.0	1.1	0.0	0.0	0.0	0.0
Slovakia	0.0	3.3	4.0	0.0	5.6	13.2

Source: Own Elaboration

Table 5 present the price change in ETD_2 scenarios. The main difference with the previous scenario is that Member States will reduce the tax on electricity up to be the least taxed energy product. Member States that are currently taxing electricity above minimum levels would face the largest impacts. For example, Denmark would have to reduce electricity tax rates to a third, partly to set the same taxation as the lowest energy product (in this case natural gas). This cut would reduce final prices of electricity by 40% in Denmark. There are also important cuts in electricity prices in Austria, (-5.1%), Cyprus (-8.2%), Germany (-5.8%), Spain (-3.6%), France (-14.3%), Poland (-11.8%) and Sweden (-4.9%) (see Table 5).

Seventeen MS are currently taxing electricity as the lowest energy product so there would be no changes in electricity in these countries. Therefore, for these Member States, Scenario ETD_1 and ETD_2 will therefore have similar price impact.

Table 5. Change in final prices by energy products and country in ETD_2

Member State	Petrol %	Diesel %	Gas oil %	Electricity %	Natural gas %	Coal %
Austria	0.0	0.0	0.0	-5.1	0.0	0.0
Belgium	0.0	0.0	3.8	0.0	2.9	11.6
Bulgaria	0.0	8.8	0.0	0.0	7.0	13.2
Cyprus	0.0	0.0	0.0	-8.2	0.0	13.2
Czechia	0.0	1.1	0.0	0.0	4.7	14.6
Germany	0.0	0.0	0.0	-5.8	0.0	33.9
Denmark	0.0	0.0	0.0	-39.9	0.0	0.0
Estonia	0.0	2.7	0.0	0.0	0.0	0.0
Spain	0.0	2.0	0.0	-3.6	0.0	5.2
Finland	0.0	0.0	0.0	-0.9	0.0	0.0
France	0.0	0.0	0.0	-14.3	0.0	0.0
Greece	0.0	0.0	0.0	0.0	2.3	13.4
Croatia	0.0	0.0	0.0	0.0	7.0	13.3
Hungary	3.9	11.8	0.0	0.0	8.8	14.5
Ireland	0.0	0.0	0.0	0.0	0.0	0.0
Italy	0.0	0.0	0.0	-0.5	0.0	9.2
Lithuania	0.0	3.0	3.3	0.0	8.1	13.4
Luxembourg	0.0	0.0	6.2	0.0	3.0	21.6
Latvia	0.0	0.0	0.0	0.0	2.1	2.8
Malta	0.0	0.0	0.0	0.0	0.0	13.4
Netherlands	0.0	0.0	0.0	0.0	0.0	9.0
Poland	0.0	10.0	0.0	-11.8	6.3	12.5
Portugal	0.0	6.3	0.0	0.0	0.0	0.0
Romania	0.0	7.2	0.0	0.0	8.0	12.9
Sweden	0.0	0.0	0.0	-4.9	0.0	0.0
Slovenia	0.0	1.1	0.0	0.0	0.0	0.0
Slovakia	0.0	3.3	4.0	0.0	5.6	13.2

Source: Own Elaboration

Funded by
the European Union

Table 6 presents the price change of ETD_3 scenario. The electricity price remains the same as in the previous scenario. However, if the net revenue for the government is negative due to the reduction in electricity tax rates, the tax rates on fossil fuels will increase to compensate for the negative revenue and in order to achieve a revenue (fiscal) neutral reform[11]. For example, Denmark would have to increase additionally tax rates in petrol, diesel, gas oil for heating and natural gas, to compensate for the negative revenues from the reduction of 40% in electricity prices (Table 6).

Nine countries will experience higher final prices on remaining fossil fuels to compensate for the electricity rate cut: Austria, Cyprus, Germany, Denmark, Spain, Finland, France, Italy, and Sweden. In the case of Poland, the revenue effect of lower electricity tax rates is lower than the new revenues from the increase in fossil fuel tax rates, so its impact would already be positive in net terms, and therefore no adjustment is necessary.

Table 6. Change in final prices by energy products and country in ETD_3

Member States	Petrol %	Diesel %	Gas oil %	Electricity %	Natural gas %	Coal %
Austria	2.8	3.2	5.6	-5.1	5.1	13.1
Belgium	0.0	0.0	3.8	0.0	2.9	11.6
Bulgaria	0.0	8.8	0.0	0.0	7.0	13.2
Cyprus	4.2	4.6	7.5	-8.2	0.0	13.2
Czechia	0.0	1.1	0.0	0.0	4.7	14.6
Germany	2.1	2.7	5.8	-5.8	4.8	74.9
Denmark	22.1	29.3	30.2	-39.9	46.3	0.0
Estonia	0.0	2.7	0.0	0.0	0.0	0.0
Spain	1.0	3.3	2.4	-3.6	1.7	11.5
Finland	1.0	1.3	2.1	-0.9	0.0	0.0
France	6.9	8.3	13.7	-14.3	13.4	28.6
Greece	0.0	0.0	0.0	0.0	2.3	13.4
Croatia	0.0	0.0	0.0	0.0	7.0	13.3
Hungary	3.9	11.8	0.0	0.0	8.8	14.5
Ireland	0.0	0.0	0.0	0.0	0.0	0.0
Italy	0.1	0.1	0.1	-0.5	0.2	9.2
Lithuania	0.0	3.0	3.3	0.0	8.1	13.4
Luxembourg	0.0	0.0	6.2	0.0	3.0	21.6
Latvia	0.0	0.0	0.0	0.0	2.1	2.8
Malta	0.0	0.0	0.0	0.0	0.0	13.4
Netherlands	0.0	0.0	0.0	0.0	0.0	9.0
Poland	0.0	10.0	0.0	-11.8	6.3	12.5
Portugal	0.0	6.3	0.0	0.0	0.0	0.0
Romania	0.0	7.2	0.0	0.0	8.0	12.9
Sweden	9.8	10.7	15.6	-4.9	11.2	0.0
Slovenia	0.0	1.1	0.0	0.0	0.0	0.0
Slovakia	0.0	3.3	4.0	0.0	5.6	13.2

Source: Own Elaboration

Finally, table 7 presents the new revenues obtained by different MS in the different scenarios. In the scenarios

[11] Prices on fossil fuels are increased proportionally to consumption.

Funded by the European Union

with exemptions, it has been necessary to adjust the revenues, considering only the consumption of non-exempt households.

In the ETD_1 scenario total revenue account for 1.971 billion€. As can be expected from the price impact analysed, Poland will be the country with the highest revenue (EUR 814 million) followed by Hungary (EUR 302 million), as they must increase energy tax rates the most to comply with the ETD. Other countries, such as Spain, will also have higher revenues because the new tax rates affect energy products with high domestic consumption.

In the ETD_2 scenario, there is an overall reduction in total revenues due to the reduction in the electricity tax rate in several MSs (-7.866 billion€). Germany, Denmark and France will have significant negative revenues [12] (-2.26 billion€, -1.105 billion€ and -4.482 billion€ respectively). Although Poland also decreases its electricity tax rates, its revenues remain positive due to higher revenues from increased taxation of fossil energy products.

In the ETD_3 scenario total revenues account for 1.163 billion€. Several MS will have a net zero impact on their national accounts due to the offsetting of lower electricity tax rates with the increase in all other energy tax rates. The remaining countries would have the same revenues as in scenario ETD_2.

Table 7. Total revenues by country and ETD scenario**.**

Member State	ETD_1 (M€)	ETD_2 (M€)	ETD_3 (M€)
Austria	0	-195	0
Belgium	99	99	99
Bulgaria	30	30	30
Cyprus	0	-27	0
Czechia	76	76	76
Germany	2	-2,260	0
Denmark	0	-1,105	0
Estonia	4	4	4
Spain	289	-325	0
Finland	0	-38	0
France	0	-4,482	0
Greece	4	4	4
Croatia	14	14	14
Hungary	296	296	296
Ireland	0	0	0
Italy	0	-68	0
Lithuania	38	38	38
Luxembourg	7	7	7
Latvia	1	1	1
Malta	0	0	0
Netherlands	0	0	0
Poland	807	290	290
Portugal	110	110	110

[12] In the case that Member states have negative revenues due to the electricity cut. In this scenario we assume that these countries will compensate this effect in their national budgets.

Funded by the European Union

Romania	93	93	93
Sweden	0	-529	0
Slovenia	13	13	13
Slovakia	57	57	57
Total EU	**1,939**	**-7,897**	**1,131**

Source: Own Elaboration

2.3 Results: socioeconomic impacts of the new ETD.

This section shows the distributional and social impacts from ETD reform. We explore the socioeconomic impacts by vertical equity domain (by income groups) and by horizontal equity domain (considering different socioeconomic and demographic characteristics), and with a special focus on gender issues. Finally, we explore how the use of new revenues can compensate households in those countries and scenarios where positive revenues are available.

2.3.1 Vertical analysis

2.3.1.1 Distributional impacts at EU level

Figure 1 shows the distributional welfare impact of the ETD scenarios by EU expenditure deciles[13], i.e., we distribute the 200.000 households as if the UE was a single economy, allowing us to explore the distributional effect of the ETD at EU level as a whole.

These results show, firstly, the low relative impact that the ETD reform will have at the EU level, regardless of the scenario analysed. This indicates that the ETD reform is very gradual in most cases, as most Member States already have higher energy tax rates than those proposed in the ETD reform. In terms of the distributional impacts, Figure 1 reveals that welfare will be asymmetric across the income distribution and scenarios. Thus, in *ETD_1*, households belonging to the first deciles (i.e., households with lower income)[14] would be more affected by the new taxation, whereas households in higher income brackets are less affected by the policy. Therefore, in line with many concerns, the fossil fuel taxation component of the ETD reform will have regressive impacts at the EU level.

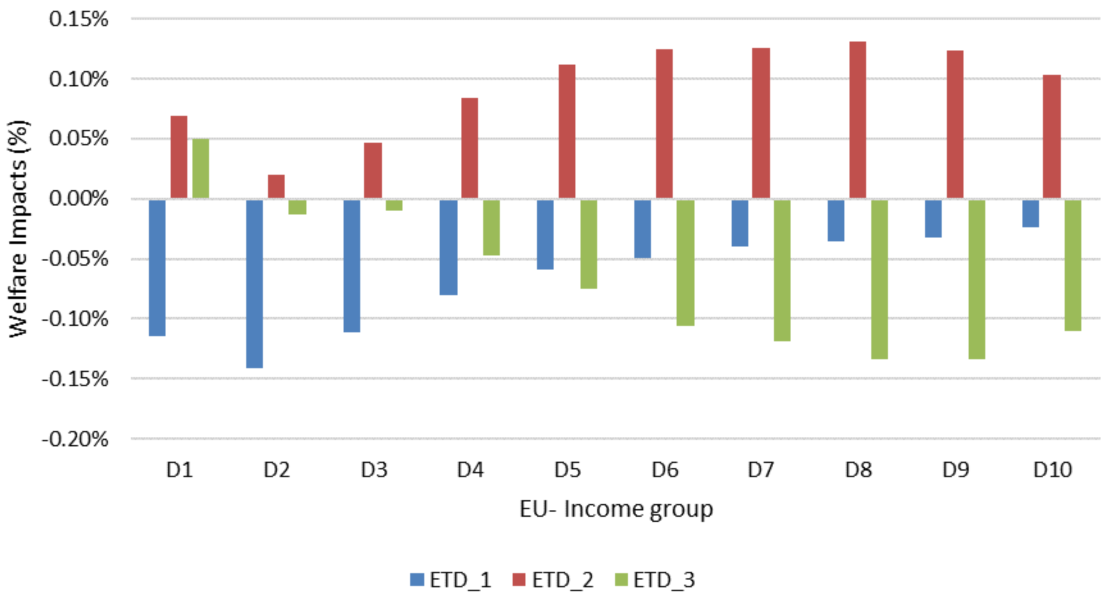
These initial results are directly related to the income distribution at the EU level, as well as the varied impacts among MS. As seen in the analysis of price impacts (section 2.2), the Central and Eastern MS would experience higher prices on energy products, given their current status as the MS with the lowest environmental taxation. Consequently, they must increase their taxation significantly to meet the ETD proposal. Simultaneously, these MS are associated with lower income groups in the EU income distribution. This explains the regressive impacts at the EU level of the new ETD, as the households most affected by the reform are in countries with lower average incomes that need to increase their current taxation more substantially. For example, the average total expenditure per capita in Poland, one of the MS most affected by the reform, is 9870, whereas the average total expenditure per capita in Denmark, barely affected by the tax increment, is 27.630.

[13] Expenditure is used since it is considered a better approximation of permanent household income (Goodman, & Oldfield, 2004). Equivalent expenditure deciles are calculated from household expenditure relativized by the modified OECD equivalence scale. The modified OECD scale values the reference person in the household at 1, all other persons aged 14 and over at 0.5, and all other persons under 14 at 0.3.

[14] According to our data and in terms of the EU average, households in the first decile at the EU level expend less than €8,500 per year, whereas the wealthiest ones (D10) expend more than €40,000. However, these ranges vary depending on the Member State.

Funded by the European Union

The income distribution among different MS and the design of the policy are also crucial for explaining and analysing the results of the *ETD_2* scenario. In this scenario, we assume that countries with electricity taxes exceeding the proposed minimum should reduce their taxation to align with the EU Commission's proposal. While in *ETD_1*, member states needing to increase their taxation on fossil fuels (diesel, gasoline, and fossil fuels for heating) are generally low-income MS (part of Central and Eastern EU, such as Poland or Slovakia), in *ETD_2*, the countries required to reduce their electricity taxation are wealthier MS in Western and Northern EU, such as Denmark, France, and others. The substantial reduction in electricity tax in wealthier EU countries explains the positive welfare impacts in the *ETD_2* scenario, with these positive impacts being more pronounced in EU middle and high-income households.



Note: D1 is lowest income households in the EU whereas 10 is the wealthiest.

Figure 1. Welfare impacts by income groups at EU level

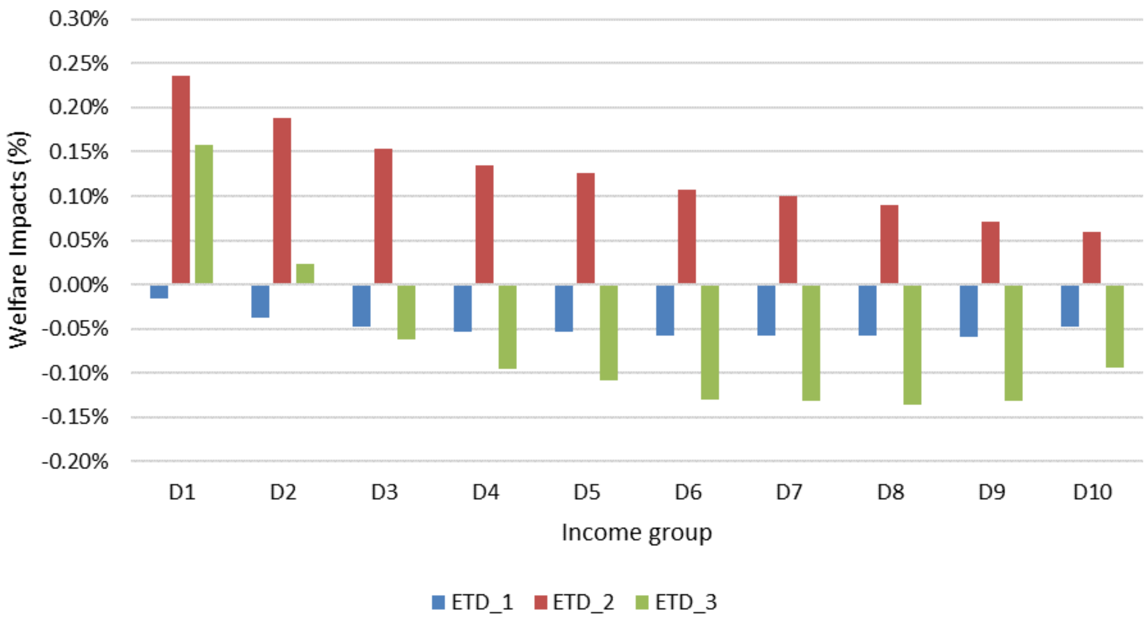
Following the same dynamic that *ETD_2*, in *ETD_3*, it is again the richest MS those that must increase their fossil fuel taxation to compensate for revenue losses resulting from the electricity tax reduction introduced in *ETD_2*. Therefore, contrary to what happened in *ETD_2*, now the EU middle and high-income groups experience larger welfare losses. While in Western EU, low-income groups may benefit from lower electricity taxation, in *ETD_3*, middle and high-income households in wealthy MS will have to dedicate a larger proportion of their income to consume fossil fuel products for transport and heating (see consumption pattern on Figure 3). This explains the progressive impact of the *ETD_3* scenario at the EU level.

The overall distributional analysis clearly shows how the design of the policy, and the implementation of the new ETD can change welfare impacts at the EU level, moving from regressive to progressive environmental tax reforms.

2.3.1.2 Distributional impacts at average national level

Although the previous analysis offers relevant insights and results about the distributional impact of the new ETD at the European level, it doesn't allow us to analyse how this policy can affect national inequality in the different MS. Therefore, Figure 2 presents the distributional welfare impact of the new ETD scenarios by national expenditure deciles of each MS.

Funded by
the European Union



Note: D1 is lowest income households in each Member States whereas 10 is the wealthiest.

Figure 2. Welfare impacts by national income groups

Although at the EU wide-level (Figure 1) we have seen that the increment of fossil fuel taxation following the new ETD (*ETD_1*) could increase the inequality at EU level, at national level the impact is less regressive and the welfare losses are higher on the middle- and high-income brackets. At the same time the *ETD_2*, where also the increment of fossil fuel taxation is accompanied with lower electricity taxes in those MS that have an electricity taxation beyond the minimum, still being clearly progressive at national level, and shows how the lower electricity taxation can compensate the higher cost of the fossil fuel commodities for many households. This positive effect is especially relevant for the lower income groups in all EU member states, as shown in the *ETD_3* scenario. Although larger fossil fuel taxations are introduced to compensate for lower revenues (*ETD_3*), when necessary, the positive effect of reducing the cost of electricity more than compensates for the possible welfare losses for the poorest households in the national distribution. This concentrates the cost of the policy on the wealthiest families in most EU Member States.

The previous distributional impacts can be explained by the consumption pattern of the European households (see Figure 3). Although this consumption pattern can differ between MSs and across the income distribution, it can show the main key driving forces that shape the distributional impacts of the policy measures distribution., as energy expenditure constitutes a significantly larger share of total expenditure of lower-income compared to higher-income households.

It is also important to note the differences between energy products, where transport fuels constitute the biggest share of expenditure of middle-income households (private car ownership being less common among lower income households) and the contrary for electricity (see Figure 3). In the context of the proposed ETD reform, expenditure on electricity makes up the highest share of household expenditure for the lowest-income households – 4% on average for the poorest 10% - higher even than expenditure on heating fuels.

In terms of the national income distribution, this means that any measures to reduce electricity prices – including the tax reductions in the proposed ETD reform (*ETD_2*)– will have substantially progressive impacts, benefiting

Funded by
the European Union

the poorest households most. By contrast, any measures that increase fossil heating fuel prices – including the tax increases in the proposed ETD reform– will have regressive impacts, adversely affecting the poorest most. Meanwhile, the impact of such measures on transport fuel prices will mostly affect middle-income households. Therefore, the consumption structures can explain the previous distributional impacts at a national level.

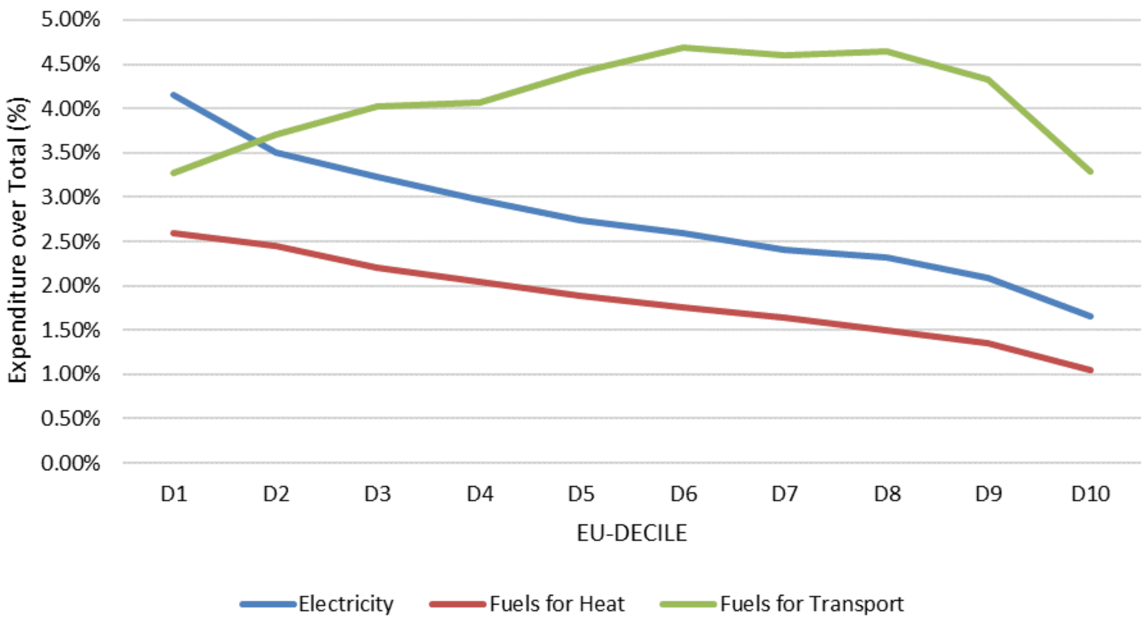


Figure 3. Energy expenditure patter in by EU-Deciles

While this is the average picture across the income distribution, there are important differences in the structure of energy consumption both between and within MSs. Average energy expenditure as a share of household income among MSs ranges from around 4% in Malta to nearly 14% in Poland, with significant differences in the shares of different fuels among the MSs. Within MSs, we find that in lower-income MSs, transport fuel expenditure tends to increase more in proportion with income compared to the EU-wide pattern of transport expenditure, while the EU-wide pattern is more typical of higher-income MSs. Electricity, however, makes up the largest share of expenditure of lower-income households across the vast majority of EU MSs. This is mainly because in lower-income households, a larger proportion of income is allocated to covering the basic needs. Electricity is a fundamental necessity for daily living and low-income households allocate a higher percentage of their income to essential utilities. Furthermore, low-income households reside in less-energy efficient housing, which lead to higher electricity consumption due to inefficient insulation and outdated appliances.

Although both analyses, the national and the EU-wide inequality, provide different results, some general messages and lessons can be extracted. First, the implementation of the new ETD will play a key role in increasing current inequalities both between and within the Member States. Hence, we have seen how the different scenarios of implementation differ in their distributional implications at the national and EU levels. Second, electricity taxation in the new ETD is essential to ensure progressive environmental taxation. As shown before, expenditure on electricity makes up the highest share of household expenditure for the lowest-income households, regardless of the Member States analysed. Thus, if the new ETD ensures that electricity is the least taxed energy product, European environmental and energy taxation will be more progressive (meaning that the tax burden is distributed in a way that considers the income levels or vulnerabilities of different households), reducing the energy costs of the most vulnerable households. Third, although some taxes on energy products can involve regressive impacts

Funded by
the European Union

and therefore increase inequality at the EU and national levels, this impact is not as clear for taxes that affect private transport fossil fuels, such as gasoline and diesel. Gasoline and diesel are more relevant for middle-income groups in Western EU MS, which can make the new ETD more proportional at the national level in these MSs. In contrast, in the Central and Eastern MSs, it is the highest income brackets that dedicate a larger proportion of their income to these energy products, and therefore the new ETD in these MSs can even turn into progressive taxation.

2.3.2 The gender dimension on the distributional impacts of the new ETD

As we mention before, despite the demands of international and European organisations to integrate gender mainstreaming into all legislation, policies, and instruments related to climate action, the gender dimension of environmental policies has not been very often addressed in depth in the European policies, as it is also the case of the new ETD. Therefore, in this section we provide new evidence from our microsimulation to assess the role that gender dimension can play when we explore the distributional implications of the new ETD.

Figure 4 shows the welfare impacts of the different ETD scenarios by the gender of the reference person of the households (i.e. the breadwinner of the households) at EU level. Moreover, trying to go a step further, we also explore the role gender has according to the number of women in the household and not solely based on the gender of the reference person. To estimate the feminisation degree, we calculate the percentage of household members who are women over 14 years and then we divide the households into 5 groups based on the share of women: 0-20% (FD1) (lower degree of feminisation), 20%-40% (FD2), 40%-60% (FD3), 60%-80% (FD4) and 80%-100% (FD5) (higher degree of feminisation).

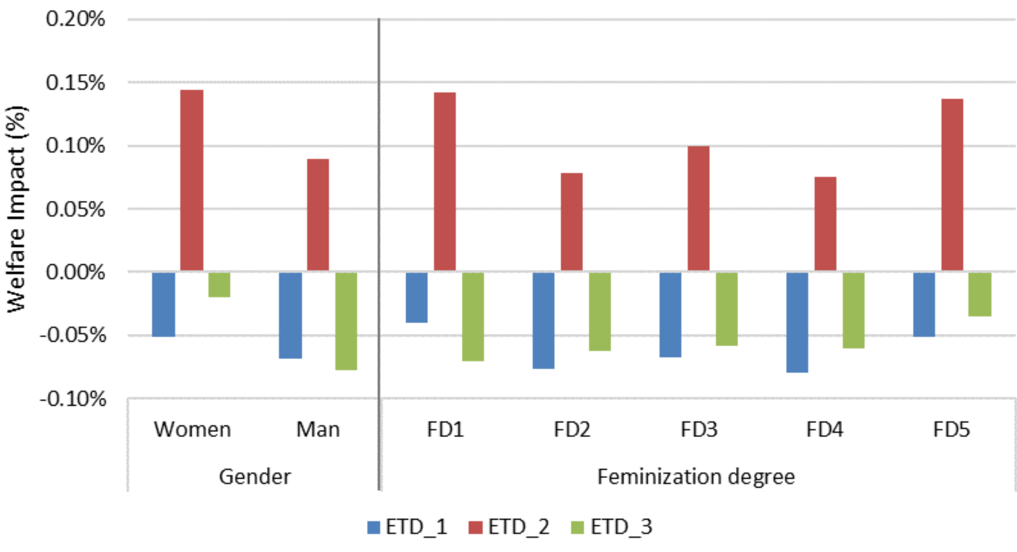


Figure 4. Welfare impacts according to the gender of the reference person and Feminisation degree of the Household

We can clearly see how the gender of the reference person plays a relevant role in the welfare impacts that we can expect from the new ETD. Hence, when the ETD involves larger costs for fossil fuel consumption (*ETD_1* and *ETD_3*), male-headed households experience larger negative impacts than those where the reference person is a woman. This impact is explained by the higher costs for fuels used in transport, as the use of car is more frequent in male-headed households. One factor that can explain this gender bias is the observation that

Funded by
the European Union

households where women are the reference persons often belong to low-income groups with distinct socioeconomic characteristics. This is evident in the case of single elder households and single-parent households, where women represent 74% and 87%, respectively, and frequently fall into the lowest income brackets across all EU member states.

However, households led by women allocate a larger proportion of their income to electricity, making them significant beneficiaries of tax reductions on electricity in the *ETD_2* scenario. They even offset almost all the extra costs resulting from higher taxation on fossil fuels, compensating for potential negative impacts from the reduction in electricity taxation (*ETD_3*). As mentioned earlier, women-led households belong more frequently to low-income households where the cost of electricity constitutes a substantial portion of their consumption baskets, whereas male-headed households do not benefit as much from the tax reduction in this energy commodity. Heating consumption follows a similar pattern in terms of gender as electricity consumption. However, heating represents a smaller proportion of income compared to electricity or transport in many households, and as such the distributional impacts are less affected by this energy consumption.

Regarding the degree of feminisation, we cannot observe significant differences when households are predominantly composed of men or women. In *ETD_1* and *ETD_2*, welfare impacts are similar for FD1 (least feminisation) and FD5 (most feminisation) households, with more noticeable differences in mixed households (FD2, FD3, and FD4). FD1 and FD5 households typically have fewer members, making them more likely to be exclusively composed of either men or women. Consequently, their consumption patterns are more similar compared to mixed households, which have more members and, therefore, exhibit more similar consumption patterns regardless of the gender composition.

The degree of feminisation appears to play a crucial role in policy performance only when costs are significantly higher for fossil fuels in transport and electricity tax reductions are implemented (*ETD_3*). The negative impacts on welfare decrease as the feminisation degree of the household increases, particularly emphasising the distinct energy usage patterns between women and men, especially in the context of private transportation. These results suggest that while the degree of feminisation can influence household energy consumption, gender becomes more significant when women hold stronger positions within the household as breadwinners.

Finally, to explore deeply the role that gender can play in the socioeconomic impacts of the new ETD, we have included an intersectional approach in our analysis, considering both gender and the feminisation degree, as well as the economic classes of different households. According to the literature (see Cho et al., 2013; Crenshaw, 1991; Djoudi et al., 2016; Kaijser & Kronsell, 2014) individuals experience oppression or privilege based on their belonging to multiple social groups and , therefore, intersectionality approaches can examine how different interconnected socioeconomic categories (e.g., class, gender, race, etc.) can be crucial in understanding the performance and impacts of a policy.

Therefore, Figure 5 and 6 show the distributional impact based on the gender of the household reference person and the feminisation degree by income quintiles. It can be observed that the distributional impacts follow a similar path in terms of progressivity or regressivity of the scenarios, as explained in the analysis of the national income distribution (Section 4.2). This demonstrates that, although gender may play a relevant role in explaining the distributional implications of the new ETD, the income profile of the households still predominantly influences the welfare impacts resulting from the different applications of the policy. However, there are some noteworthy differences to mention.

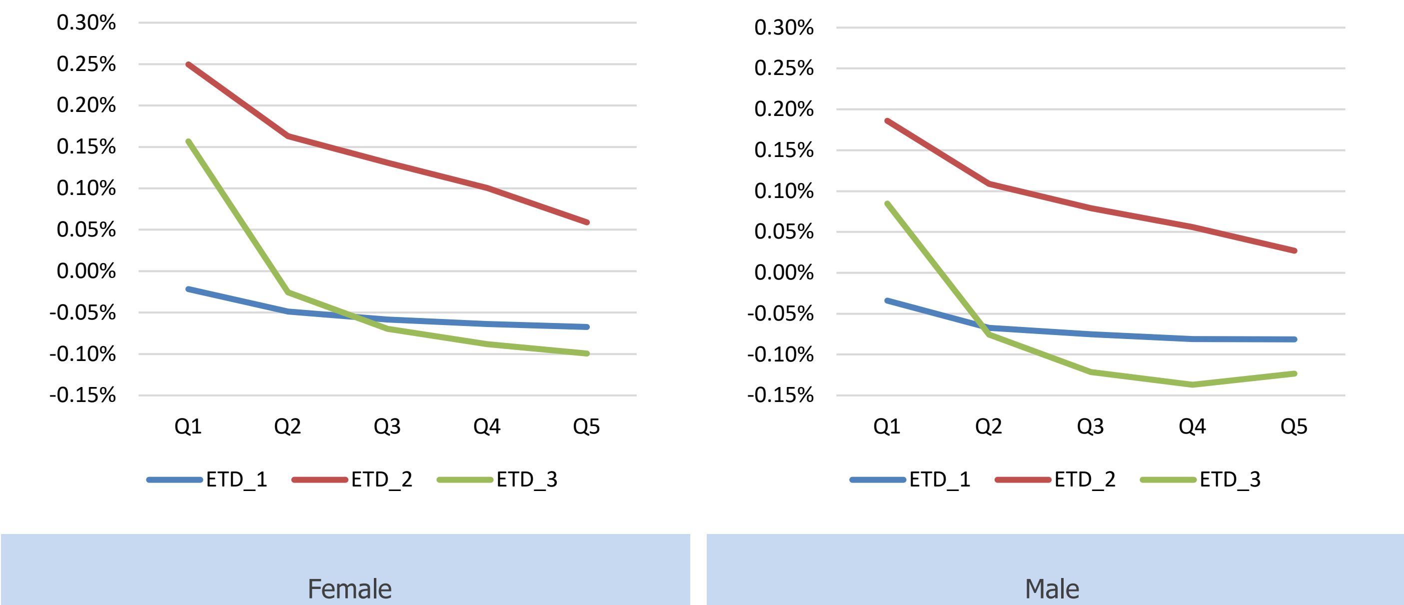
We can observe how the differences in welfare impacts between women and men, regarding the reference person

Funded by
the European Union

of the households, remain similar for all income groups. This fact reflects that the distinct consumption patterns between women and men not only depend on the economic capacity of the households, but there are also other socioeconomic factors that might explain why women have a more environmentally friendly consumption.

Likewise, concerning the degree of feminisation, the welfare impacts by scenarios also follow a pattern similar to the those of Figure 2. ETD reforms that include electricity tax reductions are more progressive, clearly benefiting low-income groups at all degrees of feminisation (*ETD_2* and *ETD_3*). However, the differences between the highest and lowest income groups decrease as the feminisation degree increases (see impacts on Q1 and Q5 in FD1 compared with FD5). This trend reflects that the consumption patterns of different income groups become more similar as the share of women in the family increases. Households with more women tend to allocate a larger proportion of their income to electricity and less to fuels for private transport, regardless of the income group. Therefore, the impacts across different scenarios by income group in these households are more similar as well (see FD4 or FD5). On the other hand, in households with more men, the income level plays a more significant role, explaining the differences in welfare impacts between low and high-income brackets (see FD1 or FD2).

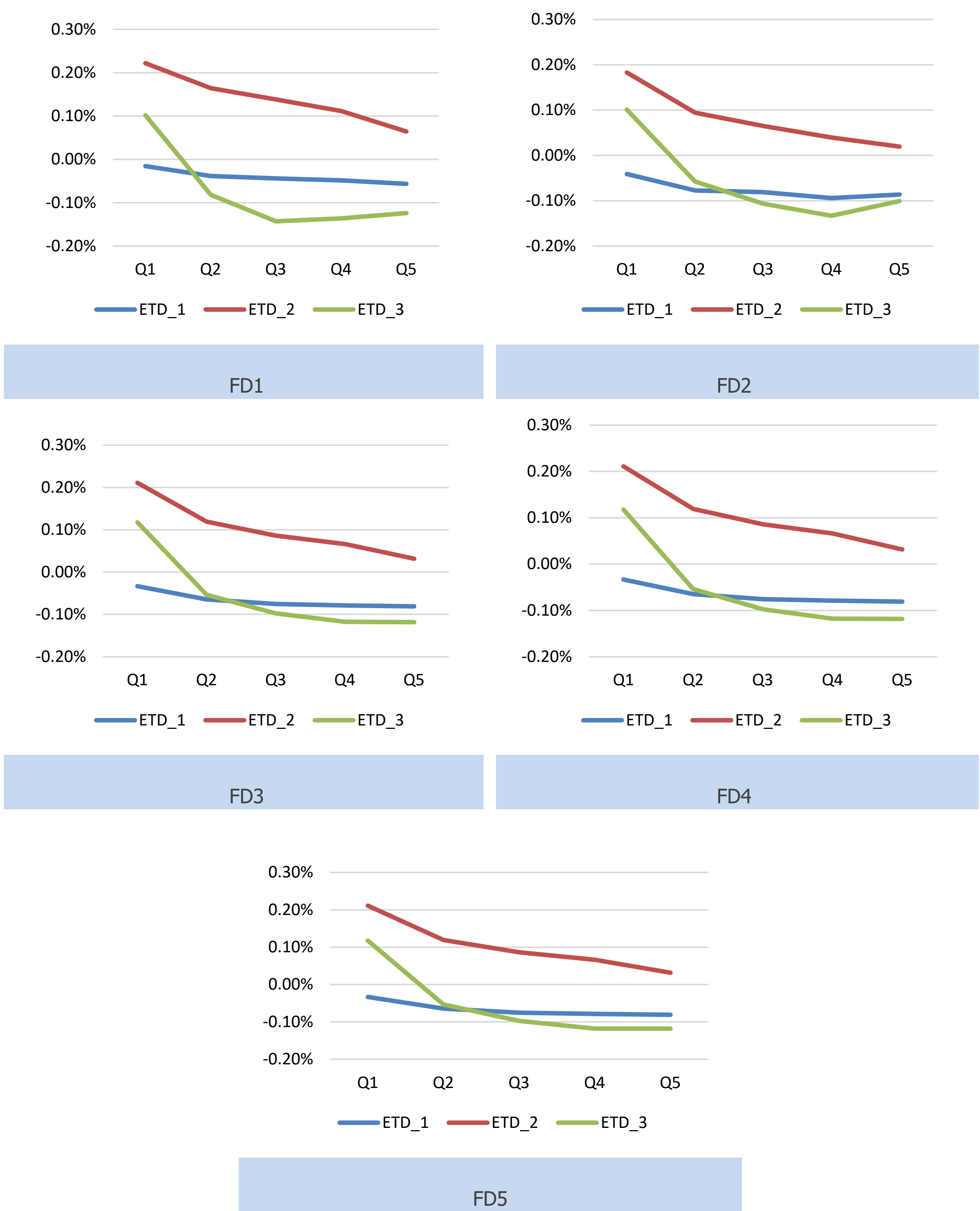
Figure 5. Welfare impact according to different socioeconomic characteristics



This demonstrates that, although income is one of the main factors explaining the impacts on households' welfare and energy consumption, especially in the dichotomy between electricity (more significant for low-income households) and fuel for private transport (more relevant for middle- and high-income brackets), gender and the feminisation degree of the households can also modify the consumption pattern and, therefore, the expected distributional impacts of the new ETD. Hence, the policy impact analysis, as well as the design of the policy, will benefit from gender mainstreaming. This ensures that the policies not only avoid increasing the gap between the rich and the poor but also address other inequalities, such as those represented by gender.

Funded by
the European Union

Figure 6. Welfare impact according to different socioeconomic characteristics



2.3.3 Other horizontal impacts

The different socioeconomic characteristics included in the database used (EU-HBS, which is the main source of data in our modelling work), allow us to develop horizontal and granular analyses, exploring impacts according to different household socioeconomic characteristics. Figure 7 shows the average welfare impact according to different household characteristics. Therefore, we can see how different characteristics play an important role for analysing the new ETD.

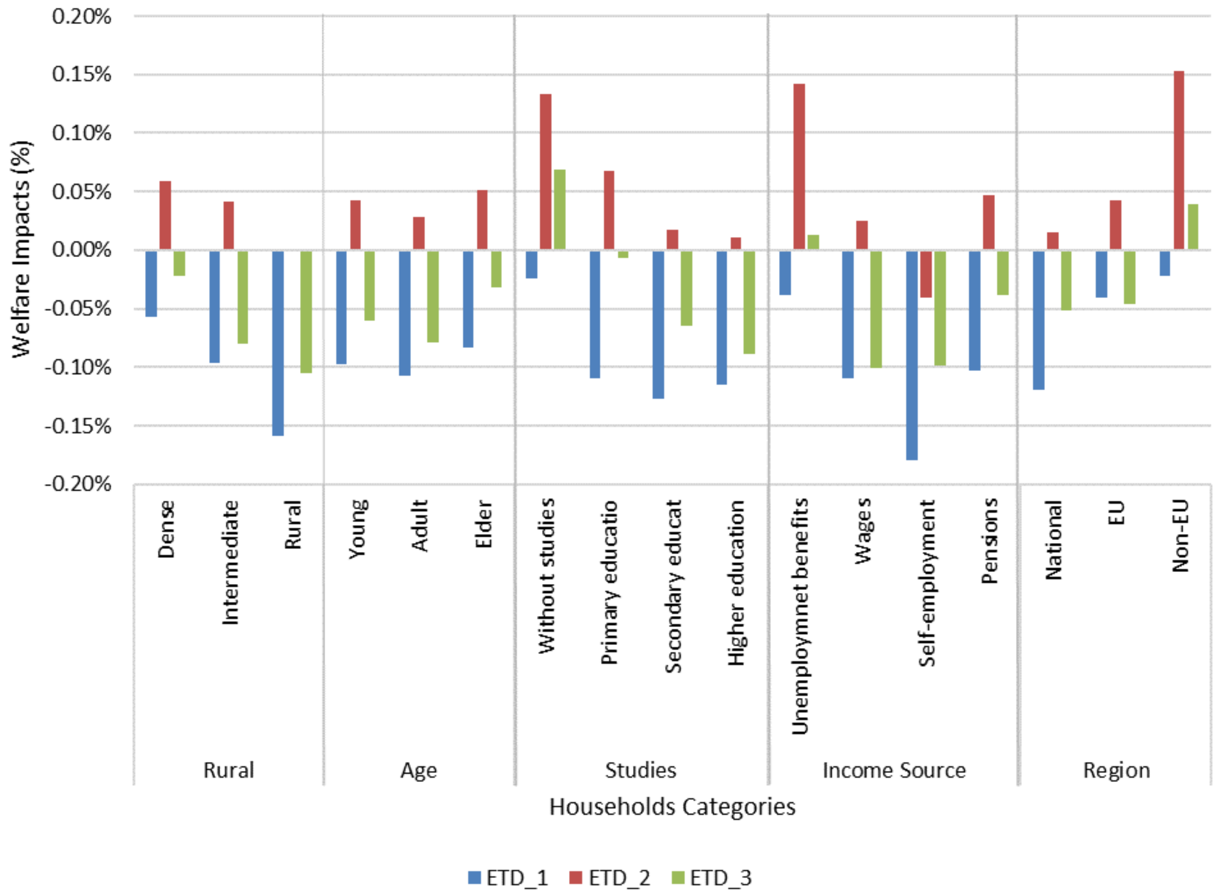


Figure 7. Welfare impact according to different socioeconomic characteristics

First, Figure 7 shows a great range of impacts depending on the scenario but also on the socioeconomic characteristics of the households. Hence, "Rural" (low density areas) and "Self-Employment" households are those harder affected by the increases in fossil fuels energy prices due the reform of the ETD. These households dedicate a large proportion of their income to mobility and therefore are more negatively affected. Residents in rural areas or areas with low population densities tend to rely more on private vehicles due to the lack of alternative public travel options and their higher mobility needs (Flues & Thomas, 2015; Tomás et al., 2020, 2023). Likewise, households in which the main income source of the breadwinner is self-employment also have higher mobility needs, as they need to commute more for work compared to those employed by others.

On the other hand, households composed of a single elderly person, whose reference person is not educated or was born outside the EU, would be the least affected by the reform of the ETD and, at the same time, would benefit the most from lower electricity taxes (*ETD_2* and *ETD_3*). These households are associated with the lowest income brackets and allocate a higher proportion of their income to electricity and a very low proportion to transportation fuel, explaining their potential welfare gains.

Funded by
the European Union

2.3.4 The capacity of the revenues to compensate welfare impacts.

Very often the distributional analysis of environmental policies and taxation are analysed in isolation from the possible uses of the new revenues, thus performing partial analyses that do not consider the capacity of these revenues to offset possible negative socioeconomic impacts.

To explore the effect of compensation mechanism we have introduced two revenue recycling scenarios on the *ETD_3* scenario: i) a scenario in which revenues are recycled through a lump sum to all the households (*ETD_3_REC_ALL*) and ii) a lump sum to the poorest 50% of households in each MS (*ETD_3_REC_D5*). We consider this analysis only for *ETD_3*.

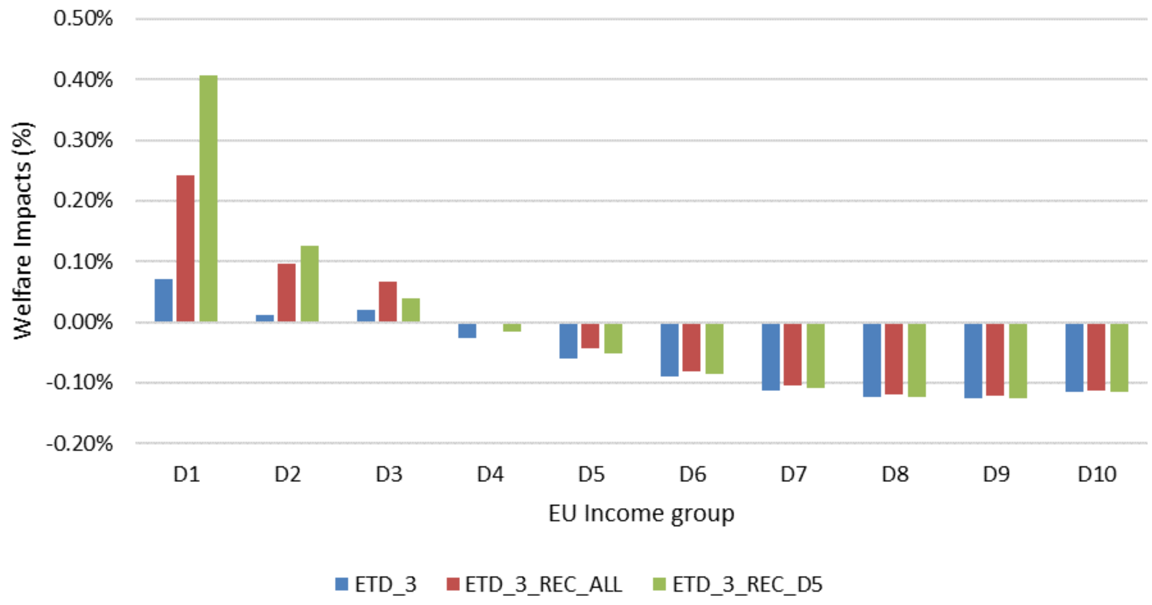


Figure 8. Welfare impact of ETD 3 with revenue Recycling schemes

Figure 8 shows the welfare impacts on EU income groups in scenario *ETD_3* compared with two revenue recycling scenarios, in which new revenues are recycled through a lump sum to all households (*REC_ALL*) or to the poorest 50% (*REC_D5*). These results demonstrate the capacity of the revenues to compensate households and increase the progressive effect of the taxation policies. Although scenario *ETD_3* is progressive at the EU level, the use of the revenues amplifies the positive effects on low-income households. On these scenarios the positive effect of reducing the electricity taxation (included in *ETD_2* and *ETD_3*) is added to the lump sum of the revenue recycling. The impact on the least wealthy households is clearly higher, as the equal lump sum has a more significant effect on their income than on wealthier households. This impact is even larger when lump sums are only used to compensate the 50% poorest households (*REC_D5*). In this case, although the revenues for recycling are the same, the number of households is fewer, and thus, the lump sums are higher compared to the *REC_ALL* scenario. Also, the more positive impact on the lowest income groups remains in both scenarios because of the previously mentioned effect.

Hence, this final analysis shows the relevance of exploring the policy package as a whole, including the use of the revenues, as their different uses would be key to the final impact of the policy reform. In this case, revenue recycling can make a policy that is already progressive even more so, thereby reducing existing inequalities across households. In other cases, it could counteract the possible regressive effect of tax reforms and result in a

Funded by
the European Union

progressive reform that is more fair and publicly acceptable.

2.4 Conclusions about the social implications of the new ETD.

The success of the targets established in the European Green Deal depends on the correct design of ambitious policies that utilise all available instruments, including energy and environmental taxation. In the "Fit for 55" package, the EC proposed a deep reform of the Energy Taxation Directive (New ETD) to update the current taxation and align it with current environmental goals. However, due to the energy crisis, and the risk of regressive effects the current proposal of the EC is stalled. Therefore, this research seeks to provide new evidence from a microsimulation model developed to assess the direct, overnight distributional impacts of the proposed ETD reform on households. Our aim is to explore whether the proposed EU-level polluter pays instruments can be designed to achieve progressive distributional impacts, and to identify policy options to ensure they strengthen and do not undermine social justice.

Our results on the overall distributional impacts demonstrate how the design and the implementation of the new ETD could transform the policy from a regressive to a progressive environmental tax reform at the EU level. Electricity taxation in the new ETD is essential to ensure progressive environmental taxation, as electricity makes up the highest share of household expenditure for the lowest-income households, regardless of the MSs analysed. Thus, if the new ETD ensures that electricity is the least taxed energy product, European environmental and energy taxation could be more progressive, reducing the energy costs of the most vulnerable households.

Moreover, although some taxes on energy products can involve regressive impacts and therefore increase inequality at the EU and national level, this impact can be offset with a correct use of the revenues of the new ETD. Hence, if revenues are used to compensate households through lump-sums schemes, progressive designs of the new ETD can make the reform even more progressive, thereby reducing existing inequalities. On the other side, it could also counteract the possible regressive effect of tax reforms and result in a progressive reform that is more fair and publicly acceptable.

Finally, we also provide new evidence from our microsimulation to assess the role that gender dimension can play when we explore the distributional implications of the new ETD. Although international and European organisations demand to integrate gender into all legislation, policies, and instruments related to climate action, the gender dimension of environmental policies has been often overlooked in European policies, as it is also the case of the new ETD. Therefore, we seek to reduce this gap by including this dimension in our analysis. Hence, our results demonstrate that, although income is one of the main factors explaining the impacts on households' welfare and energy consumption, especially in the dichotomy between electricity (more significant for low-income households) and fuel for private transport (more relevant for middle- and high-income brackets), gender and the proportion of women in households can also modify the consumption pattern (being more environmental friendly) and, therefore, the expected impacts of the new ETD. Hence, it is fundamental that the policy impact analysis, as well as the design of the policy, also includes gender mainstreaming. This ensures that the policies not only avoid increasing the gap between the rich and the poor but also address other inequalities, such as those represented by gender.

Funded by the European Union

3 Energy poverty & just transformation in Greece[15].

The European Union (EU) aims to become the world's first climate-neutral continent by 2050 (European Commission, 2019). The EU climate and energy framework, shaped by the" EU green deal", the "Fit for 55 package" and the "Clean energy for all Europeans" initiatives, entails a 55% reduction of greenhouse gas (GHG) emissions compared to 1990 levels; a 32% share of renewable energy consumption and 32.5% energy savings compared to 2005 levels. Buildings, and consequently households, responsible for 40% and 36% of the total energy consumed and CO2 emissions produced in EU respectively, play a key role to achieve these goals (European Commission, 2019). Energy poverty remains a major challenge to be further addressed in the EU. In the effort to tackle it, protect vulnerable consumers, and thus create a just energy transition to climate neutrality, policy efforts have increased, and energy poverty is a key topic in the "Clean energy for all Europeans" package (European Commission, 2019). The reduction and mitigation of energy poverty has also been increasingly targeted in energy efficiency, decarbonisation, and clean energy policies. Member States through the submission of their NECPs (National Energy and Climate Plans) indicate all the measures intended to alleviate energy poverty. In Greece, where energy poverty is a major social issue and the country scores some of the highest percentages in the EU, policy measures should be a strategic priority.

Despite the attention that the phenomenon of energy poverty has been getting the last years, and especially through the energy crisis of 2021-2022, there have been limited efforts to quantify the distributional and energy poverty implications of the transition to climate neutrality by 2050, especially for the most vulnerable households. Scientific literature is fragmented and focuses mostly on case studies. As a result, it lacks a comprehensive evaluation of distributional impacts across income deciles.

This is the first study where quantified results of the distributional impacts towards net zero energy transition in Greece are presented. In essence, we study, first, the most applicable and important policy targets with a specific focus on energy poverty and the just transition (i.e., Fit for 55 package for 2030 and Climate neutrality by 2050). Then, we simulate the distributional impacts by income decile. This simulation is performed and is fully integrated in the comprehensive, rigorous CGE modelling framework. Last, we also analyse the most relevant measures to tackle income inequality, energy poverty and create a just transition framework. These include, among others, the use of carbon revenues to reduce inequality.

This chapter is organised as follows: the strategic framework for energy poverty in Greece is described in Section 3.1, while Section 3.2 presents the indicators and methodologies used to measure energy poverty. Section 3.3, in turn, focuses on the poverty alleviation measures in Greece. Section 3.4 analyses the implications of the European Green Deal on energy poverty and equity in Greece, using a state-of-the-art macro-economic model enhanced with a representation of income deciles. Last, 3.5 provides policy recommendations while it also describes planned future work, and concludes this chapter.

3.1 Strategic framework for energy poverty in Greece

3.1.1 EU policy context

The European Commission has designed advanced and ambitious policies to tackle energy poverty, committing to protect vulnerable households. In the 2019 "Clean Energy for All Europeans" package, energy poverty was set

15 This section has been published as: Fragkos, P., Kanellou, E., Konstantopoulos, G., Nikas, A., Fragkiadakis, K., Filipidou, F., Fotiou, T., & Doukas, H. (2023). Energy Poverty and Just Transformation in Greece. In R. Bardazzi & M. G. Pazienza (Eds.), Vulnerable Households in the Energy Transition (pp. 235–267). Springer International Publishing. https://doi.org/10.1007/978-3-031-35684-1_10

Funded by
the European Union

as one of the key energy policy priorities. Although each Member State is allowed to establish its own criteria for measuring and assessing energy poverty (Faiella and Lavecchia, 2021), the need to use a common definition across Europe is well-established, to further facilitate the monitoring and mitigation of the situation—and so is the need to set clear objectives for energy poverty reduction in the National Energy and Climate Plans (NECPs) of each Member State (European Commission, 2019). In addition, provisions for dealing with energy poverty have been introduced in a series of European directives.

Indicatively, Directive 2019/944/EU[16] outlines the internal electricity market measures aiming at protecting vulnerable and energy-poor consumers in the context of the internal electricity market (social or energy policy measures to help pay electricity bills), launching investments to improve energy efficiency and/or protect consumers (including prohibition of disconnection of energy-poor consumers in critical periods), as well as providing measures other than public interventions in setting the prices for the supply of electricity. For the internal gas market, following up on Directive 2009/73/EE[17], Directive 2019/692/EE[18] details provisions for protecting energy-vulnerable households and prohibiting their disconnection in critical periods. Targeting energy efficiency, Directive 2018/2002/EC[19] outlines measures aimed at tackling energy poverty and lowering the vulnerability of consumers; while Directive 2018/844/EU[20], outlining the building energy performance framework and the long-term renovation strategy of the built environment, explicitly includes actions and measures to alleviate energy poverty among European households, according to criteria established by the Member States. Finally, Regulation 2018/1999/EU[21] (Governance of the Energy Union and Climate Action) requires that consolidated NECPs of EU Member States include estimates of the number of energy-poor households, set a national target to mitigate energy poverty, and provide progress reports including the number of energy poor households and the policy measures in place to address the issue.

It is, therefore, evident that energy poverty is high on the European Commission's agenda, especially amidst an energy crisis that is partly driven by Covid-19 recovery efforts as well as the skyrocketing gas and electricity prices caused by changing demand-supply dynamics and by Russia's invasion of Ukraine in 2022. The EU policy response included the REPowerEU strategy and national measures to reduce reliance on imported gas from Russia and protect vulnerable households from the rising energy prices. It also advocated for the adoption of behavioural changes that can boost energy efficiency. In particular, the proposed measures in the REPowerEU Plan include increasing the energy savings target (from 9% to 13% reduction in final energy consumption compared to the Reference 2020 Scenario), the diversification of the energy supply mix alongside the groundwork for a new 'joint purchasing mechanism' for gas imports, accelerated roll-out of renewable energy to replace fossil fuels (upgrading the 2030 target from 40% to 45%), and reduction of fossil-fuel use in all sectors. To support the implementation of the REPowerEU Plan, additional smart investments are deemed necessary across all sectors and levels (national, cross-border and EU). In essence, REPowerEU means that Member States strengthen any national efforts and

[16] Directive (EU) 2019/944/EU of the European Parliament and of the Council of 5 June 2019 on common rules for the internal market for electricity and amending Directive 2012/27/EU
[17] Directive 2009/73/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in natural gas and repealing Directive 2003/55/EC
[18] Directive (EU) 2019/692 of the European Parliament and of the Council of 17 April 2019 amending Directive 2009/73/EC concerning common rules for the internal market in natural gas
[19] Directive (EU) 2018/2002 of the European Parliament and of the Council of 11 December 2018 amending Directive 2012/27/EU on energy efficiency
[20] Directive (EU) 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive 2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency
[21] Regulation (EU) 2018/1999 of the European Parliament and of the Council of 11 December 2018 on the Governance of the Energy Union and Climate Action, amending Regulations (EC) No 663/2009 and (EC) No 715/2009 of the European Parliament and of the Council, Directives 94/22/EC, 98/70/EC, 2009/31/EC, 2009/73/EC, 2010/31/EU, 2012/27/EU and 2013/30/EU of the European Parliament and of the Council, Council Directives 2009/119/EC and (EU) 2015/652 and repealing Regulation (EU) No 525/2013 of the European Parliament and of the Council

Funded by
the European Union

proactive measures they had kicked off in as early as September 2021 to mitigate the impacts of the looming energy crisis (Sgaravatti et al, 2021).

3.1.2 National policy context

The Greek energy policy framework comprises laws and regulations that are largely harmonised with most of the relevant EC directives and policy measures aiming at protecting vulnerable consumers and especially low-income households. However, much like delays in harmonising national and European energy efficiency legislation in Greece (Nikas et al., 2019), important EU directives (D2019/944/EU1, D2018/2002/EU4) have not yet been fully adopted in the national policy framework.

Nevertheless, significant progress has been made in defining the categories of vulnerable consumers (financially vulnerable, dependent on continuous and uninterrupted energy supply, elderly, people with health problems, residents of disadvantaged areas), whereas several policy measures have been enforced to protect vulnerable consumers, including:

- the provision of reduced invoices, or a discount on each supplier's published invoices,
- the installation of prepaid meters,
- the provision of more favourable terms for paying the electricity and gas bills,
- the adoption of alternative ways of accessing service and bill payment services,
- the subsidisation of the electricity and fuel (oil, gas, biomass) consumption, and
- the prohibition of disconnection of such consumers during critical periods.

In addition, criteria, and procedures for the inclusion of consumers in the above measures as well as obligations of energy providers/suppliers are defined. However, since an official definition for energy poverty at national level has not yet been established (Arsenopoulos et al., 2020) and, considering the lack of a common definition across the EU, identifying the energy poor population in the country can be challenging.

In 2021, the Greek parliament approved the National Energy Poverty Alleviation Plan (NEPAP, 2021), according to the NECP (2019) provision. The plan constitutes the Greek national strategy against energy poverty for 2021-2030 and aims to outline a comprehensive understanding of the situation by mapping and analysing the characteristics of the affected households, focused on those with the highest vulnerability. The NEPAP also proposes effective planning and implementation of the necessary policy measures to achieve the quantitative goals set within the framework of the Greek NECP for a reduction by at least 50% of its relevant energy poverty indicators by 2025, and by 75% by 2030, compared to 2016 (baseline year). Specifically, the Action Plan has been based on the identification of households affected by energy poverty using specific quantitative criteria; the development of a specialised process for recording, monitoring and evaluating the course of alleviating the phenomenon until 2030; the formulation of a well-defined set of policy measures to tackle energy poverty; the development of a mechanism for monitoring and evaluating the effects of each policy measure, to assess their effectiveness or need for adjustments; and the exploration of specific schemes to address energy poverty in vulnerable households either through existing policy measures or through new ones.

3.2 Measuring the problem

3.2.1 The diversity of indicators to identify and measure energy poverty

There are three prevailing measurement methods to identify energy poverty, including (i) expenditure-based indicators that estimate the magnitude of energy poverty on a household by considering the household's energy

Funded by
the European Union

costs and income and comparing them to a selected threshold; (ii) consensual-based indicators, based on which inhabitants assess their household's living conditions, regarding thermal comfort and other conditions (humidity, insulation, etc.), and their ability to afford expenditures required to secure healthy living conditions; and (iii) direct measurement, which sets a standard for an offered energy service (heating/cooling) and assesses energy poverty against this standard (Siksnelyte-Butkiene et al., 2021). However, Thomson and Snell (2016) suggest another measurement method to identify energy poor households at local level, using welfare benefits, area-based approaches, demographic criteria, or a mix thereof.

The first method used to measure energy poverty was the ten-percent rule proposed by Boardman in 1991. The ten-percent rule identifies as energy poor those households that spend on energy expenses more than 10% of their net income. The rule has been contested about its success to identify the phenomenon when other factors (e.g., energy efficiency, social factors, etc.) are considered. Other indices proposed to face the inadequacies of this rule include the Low Income-High Cost (Hills, 2012) and the Minimum Income Standard indicator (Moore, 2012). However, these are based on inflexible thresholds that are mostly theoretical, disregard actual energy costs and the equivalised ratio between income and energy-related expenditures or the difficulties in accounting different energy services (Tirado Herrero, 2017).

Another approach on measuring energy poverty is that of Equivalisation of Modelled Energy Costs, proposed by Antepara et al. (2020) to face the problem of unreliable energy consumption data or behavioural practices due to socioeconomic factors that may modify domestic energy use patterns. This methodology models energy bills on building energy conditions and consumption patterns and relates them to socio-demographic weighted (equivalised) variables.

To integrate more aspects, several multidimensional energy poverty indices have been established in the literature (e.g., Nussbaumer et al., 2012; Bersisa, 2019; Ntaintasis et al., 2019; Crentsil et al., 2019). One of the first attempts to introduce composite indicators was that from Healy and Clinch (2002), who used 6 subjective indicators. Recently, Delugas and Brau (2018) identified energy poverty as a factor of wellbeing, Gouveia et al. (2019) combined energy performance with social and economic indicators, while Sokolowski et al (2020) combined five quantitative (monetary) and qualitative (non-monetary) indicators, aiming to address limitations of previous single- or multi-dimensional indices.

To measure energy poverty at the European level, the EU Energy Poverty Advisory Hub (EPAH) has proposed several different indicators, four primary and nineteen secondary[22]. The primary indicators comprise the shares of the (sub-) population that delay paying utility bills and that cannot keep their home sufficiently warm, calculated on the basis of answers to closed-ended questions (EUSilc); as well as household income and energy expenditure (with data from Household Budget Surveys- HBS)—e.g., energy expenses being more than twice the national average household income. However, caution is advised regarding structural differences in energy expenditure among households, situations where energy is often—albeit not exclusively—included in rent, and high energy efficiency standards or considerable underconsumption of energy. The secondary indicators include average prices paid by a household per kWh from district heating or generated from specific components such as fuel oil, biomass, and coal; electricity and gas prices for different types of consumers; energy consumption expenditure on electricity, gas, and other fuels as a share of income for 5 income quintiles; accommodation-related indicators such as average number of rooms per person in owned, rented, and all dwellings; location (densely populated or intermediate residential area); dwelling condition (leakage, dampness, or rot); and people at risk of poverty or

[22] Energy Poverty Advisory Hub https://energy-poverty.ec.europa.eu/energy-poverty-observatory/indicators_en

Funded by
the European Union

social exclusion or death in winter.

The 2030 framework of the Covenant of Mayors also commits to contributing to energy poverty alleviation[23], based on six classes of indicators: climate, facilities/housing, mobility, socio-economic aspects, policy and regulatory framework and participation / awareness-raising. The climate category includes the energy consumption for space heating and cooling a building and the frequency of hot and cold waves per month each year. Facilities or housing indicators leverage various data that may be available at the municipal level—e.g., on buildings, households, etc. This data may include energy consumption such as the percentage of municipal energy consumption per capita over national energy consumption per capita, or information on the living conditions such as the percentage of population/households with leakage, dampness, or rot in their dwelling, the percentages of households/individuals experiencing discomfort in heating or cooling and those connected to the electricity or gas grid. Indicators also report systems for heating and cooling, e.g., central heating, oil boilers, wood boilers, conventional gas boilers, and central cooling systems. There also exist indicators relating to the energy efficiency of buildings, specifically for categories F, G, H, the percentages of buildings refurbished each year that have an Energy Performance Certificate (EPC) higher than B. In addition, there are assessments on occupants, social housing flats to total flats, and social housing energy demand of the national median demand. Finally, this category is completed by indicators relating to the share of households with absolute energy expenditure above a defined share of the national average, considering the average age of buildings by period of construction, and the ratio of households/individuals relying primarily on clean fuels and related technology. The mobility category includes indicators focusing on public transport (distance to nearest station, frequency of transit to serve the public, household access to essential services by foot, bicycle, or public transport, share of social housing households without easy access to public transport, and of households receiving support to pay for public transport services). Socio-economic indicators include unemployment, inability to keep the house sufficiently warm or cool, money spent on electricity or gas consumption, citizens' spending on energy services compared to their income and national average, arrears on utility bills, age, education level, household situation (vulnerability, poverty and at-risk-of-poverty, state aid, and GDP- or income-based indicators). Policy and regulatory indicators report on the status of energy poverty strategy, incentives for owner schemes, rent regulation, and specific energy-poverty policy measures. Finally, participation/awareness-raising refers to the existence of a deterrent to rent increases due to energy retrofits, and engagement and cooperation with local actors on energy poverty.

3.2.2 Measuring energy poverty in Greece

Among the several methodological approaches for identifying energy-poor households, the Hellenic Ministry of Environment and Energy has selected the 4 EPAH indicators to make an initial assessment of the situation in the country (NEPAP, 2021). The Centre of Renewable Energy Sources and Saving (CRES), in charge of the National Observatory of Energy Poverty, has proposed an additional indicator, namely the coverage of basic energy needs per household, calculated as the ratio of actual recorded energy consumption to theoretically required energy consumption for specific uses; particular attention is paid at how required household energy uses are determined.

In the context of the NEPAP (2021), it is desirable to identify energy-poor households through a combined multi-dimensional index, which considers as many factors as possible, as proposed by Directive 2019/944/EU1 (and related to income, purchasing costs of energy products, and energy efficiency of residential buildings). Finally, an additional indicator, I&IIeq, is also included to target the households that simultaneously meet both of the

[23] Covenant of Mayors for Climate & Energy EUROPE https://www.eumayors.eu/support/energy-poverty.html

Funded by the European Union

following requirements:

- the annual cost of the total household's energy is lower than 80% of the annual cost to cover the minimum required energy consumption (Condition I), and
- the equivalised net income of each household (based on the equivalent number of household's members according to the OECD scale) on an annual basis is lower than the 60% of the median of the corresponding income for all households according to the definition of relative poverty (Condition IIeq).

According to the I&IIeq indicator's initial calculation, the percentage of affected households in 2016 amounted to 14% of all households (approximately 573,000 households). The latest progress report[24], issued in 2021, calculates the I&IIeq at about 12% (approximately 497 thousand households). Continuous evaluation of this indicator to measure energy poverty is a priority, to make adjustments to policy measures and regulations as needed according to new scientific evidence on the factors that impact energy poverty.

3.3 Energy poverty alleviation measures in Greece

National efforts to deal with the situation in Greece follow the NECP (2019) and NEPAP (2021) provisions. Actions are promoted towards three axes: consumer protection (financial support to households affected by extreme conditions of energy poverty, and protection through regulatory measures), energy efficiency and RES diffusion (financing measures with long-term impact, such as improvement of deep building renovations, energy efficiency improvements, and increased use of Renewable Energy Sources), and informative and training actions for affected consumers and professionals of energy saving actions. All actions that have been implemented or are currently in place today are listed in Table 8.

Table 8. Energy poverty alleviation measures in Greece

Name	Description	Beneficiaries	Put in force	In place as of fall 2022
Social Household Tariff	Special tariff to reduce electricity prices for vulnerable households, provided by all electricity providers, since 2011. The subsidy is provided for a certain amount of energy (kWh) per month and is higher for energy-poor households.	Vulnerable & energy poor households	2011	Yes
Solidarity Services Tariff	Tariff of reduced cost, applicable to public legal entities and NGOs, who provide social care services, provided by all electricity suppliers.	Legal entities and NGOs on social care sector	2013	Yes

[24] Annual Progress Report of the National Energy Poverty Alleviation Plan, year 2021, December 2021, Version 4 (https://ypen.gov.gr/wp-content/uploads/2022/04/SDEE-Annual-report-2021-v4-14032022-clean.pdf)

Funded by
the European Union

Heating allowance	A heating allowance to households for consumption of subsidised types of heating fuels or thermal energy, due to increases in the final price of specific energy products; in 2021, biomass (firewood, pellets) was added to fossil fuels. The allowance is given according to defined criteria (income, place of residence, etc.).	Vulnerable & energy poor households	2012	Yes
Electricity allowance - PowerPass	Subsidy of electricity bills to consumers with variable tariffs, starting in 2022 amidst the energy price spikes following gas supply cut-offs associated with (policy responses to) Russia's invasion in Ukraine. Its amount and beneficiaries are determined by the government based on social and economic criteria.	All energy consumers	2022	Yes
Replacement of old, energy-consuming electrical appliances (Recycle-Replace appliance)	A 2022 subsidy for replacing old, high-consuming electrical appliances (air conditioners, refrigerators, and freezers) with new, more efficient ones. The subsidy is higher for low-income households.	All households	2022	Yes
Horizontal electricity subsidy	A subsidy provided by the "Energy Transition Fund" to support electricity end-users. It is applied to all consumers without exception, regardless of income or other property criteria (households, businesses, etc.). The amount of the subsidy per MWh varies by type of consumer's tariff and consumption and is increased for energy-poor households.	All energy consumers	2022	Yes
Horizontal gas subsidy	A subsidy provided to all gas consumers (households and	All gas consumers	2022	Yes

Funded by the European Union

	businesses) to support them against the increased gas prices. The subsidy is applied to all consumers without exception, regardless of income or other property criteria, and it is foreseen to cover 50% of the last year increases. The subsidy size per MWh varies according to the consumer's tariff.			
Biomass grant	A grant dedicated to the supply of firewood to citizens residing in mountainous areas, supporting them to cover part of their winter needs for biomass. The implementation of the action is promoted collectively or individually and is supervised by the relevant forestry authority per geographical area.	Citizens of mountainous municipalities	2022	Yes
Fast-track reconnections	One-off special aid (only for 2021) to support low-income consumers, who have been disconnected from the electricity supply network due to arrears. The purpose of the allowance is to enable them to submit a reconnection request and grant them a fast-track reconnection even if the arrears remain.	Extreme energy poor households	2021	No
Regulatory package	Measures for the protection of vulnerable electricity/gas consumers that bind all energy providers through the Supply Code Amendment. The measures include an extension of the deadline (to at least forty days) for paying the bill and flexible facilitation in the payment methods, suspension of supply cuts due to arrears during the winter and summer periods, strict conditions for contract termination, etc.	Vulnerable & energy poor households	2016	Yes

Funded by the European Union

Households Energy retrofits subsidies	Increased funding from financing tools for retrofitting interventions aimed at houses of low energy efficiency, belonging to low-income citizens that are unable to afford all residence upgrade expenses. The interventions concern deep renovations of the buildings, installation of efficient, low-carbon heating and cooling systems (e.g., heat pumps), and installation of RES technologies with storage.	All households	2011	Yes
Tax deduction for renovation costs	Taxpayers implementing building renovations that include energy efficiency interventions can use this incentive to reduce their final tax. 40% of the cost of the works is deducted from the annual taxable income (spread to a period of 4 years).	Citizens	2021	Yes
"Save-Renovate for Young People"	A subsidy to homeowners (aged 18 to 39) of up to 90% for energy efficiency interventions and 30% for renovation works to their residence.	All citizens aged 18 to 39	2022	No
Support of Just Transition Plan to Coal regions	Interventions foreseen for 10,000 vulnerable households, especially in the areas covered by the Just Transition Plan. Financial support is provided for the radical renovation of homes, with a subsidy of up to 90%, in combination with the installation of RES systems. The establishment of energy communities to address energy poverty is also foreseen.	All households within the Coal Regions	2021	Yes
Energy communities	Actions to support vulnerable consumers and address citizens' energy poverty through the scheme of energy communities	All households and energy consumers	2018	Yes

Funded by the European Union

	(Energy communities, 2018). Indicative measures include renewable energy supply or use of virtual net metering, communication activities, home energy retrofits, or other relevant actions that reduce energy consumption for vulnerable homes.			
Implementation of technical and/or behavioural measures (Energy efficiency obligation schemes)	Energy businesses (fuel and energy service providers, electricity suppliers etc.) are obliged to contribute to national energy saving and efficiency targets by using their own capital to promote technical and/or behavioural support to (vulnerable) households. Measures taken to support energy poor households provide them with a premium coefficient on calculating achieved energy savings. Modifications are expected to cover large scale interventions.	All households	2017	Yes
Net-metering subsidy	A subsidy provided to at least 250,000 roofs PV units for net-metering expansion. Beneficiaries include households and small businesses in urban and rural areas, covering (part of) their electricity needs through solar energy. The subsidy is intended to cover 40%-60% of the investment.	Households and small businesses in rural and urban areas.	Expected in 2022	No
Energy poverty alleviation subsidy for municipal actions through energy communities	Subsidies to municipal and regional authorities to establish energy communities and install RES units to support vulnerable consumers and mitigate energy poverty in their citizens. The subsidy is intended to cover up to	Vulnerable and energy poor households	Expected in 2022	No

Funded by the European Union

	100% of the costs of setting up the Energy Communities and implementing the relevant investments.			
Communication and education	Provision of targeted communication and training actions for affected households, and of professionals involved in supporting these households (facilitation practices for covering energy costs, awareness on existing protection measures, availability of financing to improve energy efficiency, etc.).	Energy poor and vulnerable households, Professionals	Expected in 2022	No
Price Comparison Tool of energy products.	A platform for comparing prices and terms of tariffs offered by electricity and natural gas providers. Complaints and requests to network operators and electricity/gas service providers can be accepted, with monitoring of the progress of said request.	All energy consumers	2020	Yes

3.4 Implications of the European Green Deal on energy poverty and equity

This section aims to analyse the accruing impacts if the EU implements the Fit-for-55 target of reducing its greenhouse gas (GHG) emissions by at least 55% in 2030, compared to 1990 levels, and then achieves the goal of climate neutrality by 2050. This requires the adoption of strong climate policies (e.g., high carbon pricing) to drive a complete restructuring of the EU and Greek energy system towards renewable energy technologies, clean fuels, and energy efficiency improvements. However, high carbon pricing would entail large-scale economic restructuring directly impacting the production, demand, and competitiveness of different sectors. The decarbonisation of the energy system is not expected to impact uniformly all sectors of the economy, with large reductions expected in carbon-intensive activities, such as mining/extraction, refineries, and fossil-based power generation. These changes in the structure of energy-economic systems will be accompanied by changes in fuel and electricity prices as well as changes in financing requirements: the purchase and operation of energy and electrical equipment/appliances will change with increasing capital expenditures (CAPEX) and lower operating and fuel purchase expenditures (OPEX).

The implications of decarbonisation on economic systems are manifested via large changes in capital and labour markets, which in turn impact activities of all economic agents. Strong carbon pricing may also cause regressive distributional impacts, disproportionately affecting disadvantaged population groups that face high energy expenditures as a share of their income combined with difficulties in accessing low-cost funding. The imposition

Funded by the European Union

of additional taxes on energy products would increase the risk of energy poverty along with other challenges that low-income households in Greece and the EU face.

The analysis in this section is based on the state-of-the-art GEM-E3-FIT model, a computable general equilibrium (CGE) model for assessing the implications of energy and climate policies. Typically, general equilibrium models feature a single representative household in each national economy that averages incomes and consumption patterns. However useful when large-scale modelling is required, this aggregation may mask critical insights regarding social and distributional implications of climate policies among diverse households; distributional impacts refer to how costs and benefits of a policy or sets of policies are distributed among different regions, sectors, and households. Ignoring such distributional effects in climate policymaking may result in regressive distributional impacts and increased societal inequalities due to the lack of measures to mitigate negative impacts on vulnerable population groups. For this reason, GEM-E3-FIT is further expanded to represent ten household income classes in EU Member States, to consistently capture the potential distributional impacts of ambitious energy and climate policies for Greece until 2050 (a detailed description of the model expansion can be found in Fragkos et al 2021).

3.4.1 Inequality and energy poverty indicators

Rising income inequality is a global concern, implying that economic growth is not inclusive, and its benefits are not equally distributed to all households (EC, 2017). Income inequality can reduce economic growth, while raising concerns about sustainable growth, as the gap between rich and poor widens (EC, 2018). Income inequality is defined as inequality in earnings received from employment, private income from investments and property, transfers between households, state benefits, pensions, and rent (UN, 2015).

There has been considerable debate on the drivers of income inequality (IMF, 2015), which typically include:

- changes in labour market, which directly impact unemployment and the distribution of wages—e.g., part-time and temporary employment, gender gap, workers with low labour skills who are commonly the first to be substituted (OECD, 2011)
- labour institutions, which may lead to reduced wage dispersion (IMF, 2015)
- technological change, which increases productivity and well-being but requires higher skilled labour contributing to increased inequality—e.g., digitisation and automation changing occupational structures with replacement of routine-based jobs (OECD, 2011)
- trade globalisation, which tends to widen the income gap, negatively influencing the wages of unskilled labour despite trade increasing competitiveness and efficiency, thereby boosting economic growth (IMF, 2015)
- financial globalisation, which facilitates efficient international allocation of capital but can also aggravate income inequality, since foreign direct investments are mostly directed to technology development, increasing demand for high-skilled workers (Furceri and Loungani, 2013)
- education, which determines occupational choice, access to jobs, and the level of wages (Stiglitz and Greenwald, 2014);
- redistributive policies, with tax and transfer systems playing a major role in income equality, with types of taxes and socially security contribution having different impacts on inequality (OECD, 2012)
- household composition and ageing population (Bubbico and Freytag, 2018),
- distribution of wealth, as return on capital is a large source of households' income (Piketty, 2014, Cagetti and De Nardi, 2008).

Funded by
the European Union

Most of these drivers are featured in GEM-E3-FIT modelling framework, including:

- a detailed representation of the labour market with endogenous involuntary unemployment for five different occupation and skill types
- endogenous technological change through learning by doing and learning by R&D, particularly for low carbon technologies
- a detailed representation of ten income classes through multiple households
- endogenous bilateral trade of goods and services
- an endogenous representation of human capital development and the decision of households for education enabling an upgrade of skills
- a detailed representation of direct and indirect taxes, subsidies, and other benefits

The table below includes the most common indicators to measure income inequality. The Gini coefficient is the most established and popular indicator, while the decile dispersion ratio presents the ratio of the average income of two deciles. However, this indicator does not use information about the distribution of income within deciles and does not provide information about incomes in the middle of the distribution. Other indicators have been developed to improve understanding about income distribution, e.g., the Generalised Entropy family (e.g., the Theil index) and the Atkinson index.

Table 9. Indicators to measure income inequality

Indicator	Description/ relevance for inequality
Mean and median income by household	The mean income is the amount obtained by dividing the total aggregate income of a group by the number of units. The median is the income level that divides the population into two groups of equal size. The use of the median corrects potential distortion that may be caused by the existence of extreme values.
Decile dispersion ratio	This measure presents the ratio of the average income of e.g., the richest 10% of the population divided by the average income of the poorest 10% (Haughton, and Khandker, 2009). The indicator is vulnerable to extreme values and outliers.
S80/S20 income quintile share ratio or 20:20 ratio	Comparing the income received by the top 20% of the population with the bottom 20% of the population.
Gini coefficient	The Gini coefficient is based on the Lorenz curve, a cumulative frequency curve that compares the distribution of income with the uniform distribution that represents equality. It represents the extent to which the distribution of income differs between an equal distribution (Gini coefficient of 0) and perfect inequality (Gini coefficient of 1).
Atkinson index	This index is based on the Gini index and includes a sensitivity parameter, which can range from 0 (meaning indifference about the nature of the income distribution), to infinity (where the focus is on the lowest income group) (De Maio, 2007).

Funded by
the European Union

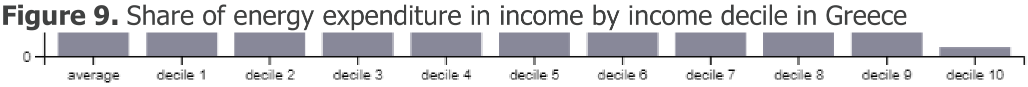
At risk poverty rate	The share of people with an equivalised disposable income below the at-risk-of-poverty threshold, which is set at 60% of the national median equivalised disposable income (Eurostat, 2019).
Severely and materially deprived	It reflects the inability of a household to afford some goods and services considered to be necessary for an adequate life (Eurostat, 2019). The indicator measures the share of population that cannot afford three (material deprivation) or four (severe material deprivation) of the nine items listed in a reference year.

The analysis of distributional impacts focuses on the income changes between deciles. The indicators of income inequality can be estimated using a combination of modelling results, and additional income data. This chapter focuses on the Gini coefficient and the Decile Dispersion ratio (S80/S20), as these indicators complement each other[25].

Extreme poverty and income inequality have decreased globally after 2000, largely owing to the decrease of inequality between countries (Revengaand Dooley, 2019). In 2020, the Gini coefficient for the EU was 30.0, compared to 30.2 in 2010, showcasing stability in income inequality. Bulgaria has the highest Gini coefficient, while the lowest inequality in the EU is observed in Belgium, Finland, Czech Republic, Slovenia, and Slovakia (Eurostat, 2019). Greece registers a value close to the European average, with signs of inequality reduction in the last decade (the Gini coefficient declined from 32.9 in 2010 to 31.4 in 2020). In 2020, the EU-28 S80/S20 ratio was 4.9, implying that the richest 20% of the population receives about five times higher income relative to the poorest 20%. This share has been stable in the 2010s. Greece ranks slightly higher than the EU average, but with clear signs of reducing inequalities, with the S80/S20 indicator declining from 5.61 in 2010 to 5.23 in 2020.

A combination of energy-inefficient housing and appliances, high energy prices, and low-income levels typically determine if a household is at risk of energy poverty (Pye et al., 2015, Gouveia et al., 2019). Our study focuses on expenditure-based indicators to assess energy poverty dynamics that can be quantified using GEM-E3-FIT model outcomes on energy expenditure and income per decile, in particular the share of energy expenditure in income (2M). This indicator measures the share of households, whose share of energy expenditure relative to their disposable income is more than twice the national median share. The highest income group has a very low share of households in energy poverty (Bouzarovski et al, 2020, as the richer a household is, the lower the share of income is dedicated to energy expenditure. The proportion of households whose share of energy expenditure in income is more than twice the national median share is estimated at 16.2% in 2015 in the EU, with Greece being very close to the EU average (Figure 9). However, this hides remarkable differences across income deciles in Greece, with more than half of those in the first decile facing substantial energy poverty risks[26].

Figure 9. Share of energy expenditure in income by income decile in Greece



[25] For example, the Gini coefficient is particularly sensitive to income differences around the centre of the distribution and thus it should be used in combination with the S80/S20 ratio that gives information about the distribution between lower and upper deciles. It should be noted that changes in within-group inequality are not measured in GEM-E3-FIT, thus losing information on inter-group income disparities.
[26] https://energy-poverty.ec.europa.eu/energy-poverty-observatory/indicators_en

Funded by
the European Union

3.4.2 Modelling income inequality and energy poverty with GEM-E3-FIT

Macroeconomic models enhanced with a representation of different socio-economic groups (e.g., income classes) can be used to evaluate the distributional implications of climate policies. Despite the challenges in terms of data integration and computational modelling issues, the introduction of multiple households enhances the capability of conventional macroeconomic models to assess income distribution effects (Zhang 2019). The representation of multiple households in CGE modelling has been long established (Cockburn, 2001, Rutherford et al., 2005, Balasko and Tourinho, 2014) but is usually constrained by limited data availability. There are ways to differentiate households, but income class is the most relevant for distributional analysis. The main caveat of this approach is that it does not capture inequality within the income deciles and the fact that households can switch deciles and change compositions (CPB, 2011).

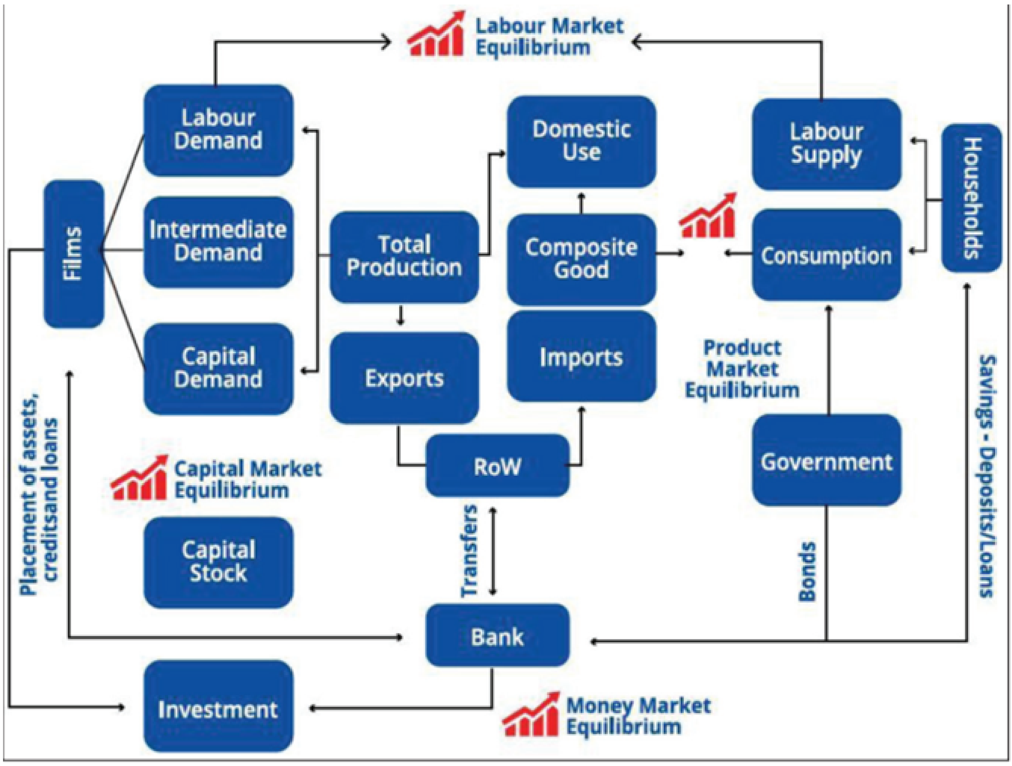
GEM-E3-FIT is multiregional, multi-sectoral, recursive-dynamic, providing details on the macro-economy and its complex interactions with the environment and the energy system. The model has been recently enhanced with a representation of ten income classes aiming to assess the distributional implications of climate policies. It simultaneously represents 46 regions (including the EU countries individually) and 53 activities linked through bilateral trade flows and runs until 2050 (E3Modelling, 2017). It covers the interlinkages between productive sectors, consumption, labour and capital, bilateral trade, investment dynamics, and price formation of commodities. GEM-E3-FIT formulates the supply and demand behaviour of economic agents that are assumed to exhibit optimising behaviour while market derived prices are adjusted to clear markets. It allows for a consistent comparative analysis of policy scenarios as it ensures that the economic system remains in general equilibrium.

Industries operate within a perfect competition market regime and maximise profits, considering the possibilities of input substitutions between capital, labour, energy, and materials. Household demand, savings, and labour supply are derived from utility maximisation using a linear expenditure system (LES) formulation. Households receive income from labour supply and from holding shares in companies. Investment by sector is dynamic, depending on adaptive anticipation of capital return and activity growth by sector. A distinctive feature of GEM-E3-FIT (Figure 10) is the representation of imperfect labour markets through involuntary unemployment, simulated by an empirical labour supply equation that links wages and unemployment levels for five labour skills.

Various policy instruments can be represented in GEM-E3-FIT, including energy and climate measures, and their interactions with policies related to labour market, economy, trade, and innovation. Policies are evaluated based on their impact on sectoral growth, income distribution, employment, economic competitiveness, and GDP. GEM-E3-FIT can assess the impacts of market-oriented policy instruments, such as carbon taxes and pollution permits, and investigate market-driven structural changes. It can analyse policy impacts in the allocation of capital, income, trade, and labour, and provide insights on compensating measures aiming at alleviating adverse distributional effects among and within countries.

Funded by
the European Union

Figure 10. GEM-E3-FIT model structure



The representation of multiple households in CGE models is a challenging task both from a computational and data point of view (Zhang, 2019). In the current study, this is implemented with a linkage of the CGE GEM-E3-FIT model with a satellite module with multiple households, through a sequential exchange of prices, incomes, and demands until an equilibrium point is established (Rutherford and Tarr, 2004, Rausch et al., 2011). This approach is easier to implement in large-scale CGE models with manageable computational complexity (compared to the hard-link approach) and it is thus adopted in GEM-E3-FIT. This was driven by the empirical findings of T. Rutherford and D. Tarr (2004), who showed very limited benefits from using the hard-link representation compared to the sequential approach. Considering the large geographic and sectoral granularity of the model and the need for short running time, we adopted the soft-link approach in the current study. The methodology is described in detail in Fragkos P. et al. (2021).

The equivalised disposable income by decile is used to calculate inequality indicators, but GEM-E3-FIT produces total disposable income by decile. The estimation of equivalised disposable income can be implemented by assuming that the equivalised household size by decile remains constant over 2015-2050 combined with a simplified assumption about the number of households by decile. GEM-E3-FIT results on income by decile can be used to quantify the Gini coefficient, by estimating 10 points of the Lorenz curve, each one representing an income decile group. The area under the Lorenz curve can be calculated by summing the areas of the 10 trapeziums, allowing to estimate the Gini coefficient as equal to the area below the line of perfect equality minus the area calculated below the Lorenz curve divided by the area below the line of perfect equality (0.5). The decile dispersion indicators (S80/S20 ratio) can be directly estimated via the income by decile quantified by GEM-E3-FIT. The disposable income of the last two and first two decile groups is utilised to calculate the S80/S20 indicator using GEM-E3-FIT results.

The "share of energy expenditure in income" indicator is used to identify energy poverty and can be estimated using the decile's total energy expenditure and total disposable income. However, this indicator requires

Funded by the European Union

information on the distribution of absolute energy expenditures and incomes on household level to derive changing median values. GEM-E3-FIT cannot provide the median of these indicators; thus, we estimate only an adjusted 2M indicator using the model output (i.e., the average share of energy expenditure in income by decile). While this approach does not reflect the unequal distributions within a decile, it provides insights regarding the economic burden of energy-related expenses on household budgets. In the analysis below, two indicators are used to measure the impacts of decarbonisation by decile group, namely "the share of energy expenditure for fuels and electricity in household income" (Indicator 1) and "the share of energy expenditure for fuels/electricity and energy equipment in household income (Indicator 2)".

The integration of multiple households in GEM-E3-FIT requires data for disaggregating household expenditure by product category and income class, household earnings by branch and income class, and data for calculating energy poverty indicators. Two key data sources are used: the EU Survey on Income and Living Conditions (SILC) and the Household Budget Survey (HBS)[27]. We use SILC data for disaggregating income sources and HBS data for detailing household consumption and calculating expenditure-based energy poverty indicators. Income and expenditure disaggregation are based on the micro data on an average per-household level and per income decile. Data for each country and for each income decile is extracted from the SILC and HBS microdata for the latest available year, including data for the structure of population (e.g., number and size of households, occupation), income (income sources per occupation, benefits, transfers, allowances, dividends and property income, and saving rates), expenditures (taxes, transfers, and consumption per purpose), and indicators on energy poverty and income inequality. It should be noted that the model-based development and data analysis is conducted at muti-regional pan-European level (with a focus on Greece) as other European countries influence the national Greek economy through various modelling channels, including international trade, technology innovation, capital and labour transfers.

Income deciles are constructed using national household sample weights included in the HBS dataset and each household in the dataset is assigned to a decile. Subsequently, average expenditures of households within each decile by Classification of Individual Consumption by Purpose (COICOP) category are calculated, using sample weights to obtain the actual distribution in the population. For energy expenditure and net income, standard deviations and skewness by income decile are calculated in the same way. To calculate the average share of energy expenditure in household income by decile, household energy expenditures are divided by incomes. Then, weighted averages, standard deviations, and skewness by country and income decile were calculated, using household sample weights. Data for other variables are extracted from the SILC database: total gross and disposable incomes, decile-specific top cut-off points, standard deviations, skewness, income per occupation (ISCO-88), tax payments, income from other sources: various household and personal-level benefits and transfers, interests, properties, and pensions.

Two key data-related challenges have emerged: the first relates to data structure that represents how individuals are nested in households, and the second to GEM-E3-FIT representing only household income. As household-level information is key to macroeconomic modelling, we assigned household-level income deciles to individuals for calculating resulting per-capita averages and per-decile totals. For most variables, macro-level data published by Eurostat cannot be replicated and thus Eurostat data is used for calculating the respective shares.

[27] Both datasets provide relevant information to characterise the different households but have methodological differences; EU-SILC largely focuses of income data at EU level, while the HBS comprises data on household consumption expenditures. HBS and SILC data are based on different samples and cannot easily be matched, as income data vary considerably. SILC data is harmonised across EU countries by Eurostat, while the HBS data are gathered by national statistical offices in a partially harmonised manner (harmonised multi-regional HBS data are published for selected years), not ensuring comparability between countries.

Funded by
the European Union

3.4.3 Scenario design

The Reference (REF) scenario is a projection of the future evolution of the global economic and energy system based on existing trends, exogenous assumptions, and scientific expertise on specific fields. Socioeconomic developments replicate IEA assumptions (IEA, 2019) and are consistent with the SSP2 scenario widely used by the IPCC. For the EU, socioeconomic assumptions are based on the Ageing Report of the European Commission (EC, 2018). The scenario assumes that already adopted climate policies and pledges, including the Nationally Determined Contributions (NDCs), are implemented by 2030. After 2030, no additional emission reduction effort is assumed, implying that the carbon prices resulting from NDCs in 2030 are kept constant until 2050. The costs of power generation and other energy technologies are calibrated to IRENA (2020), while technology progress is included for low-carbon technologies. ETS carbon revenues are recycled through the public budget.

We also develop a scenario consistent with the Paris Agreement goal to limit global temperature increase to well-below 2°C, which is proxied with the imposition of a global cumulative CO_2 budget of 1000 $GtCO_2$ over 2010 in line with the IPCC 6th Assessment Report (IPCC, 2022). A universal carbon price is implemented from 2020 onwards to reach the global cumulative CO_2 budget. As the stringency of the mitigation effort increases over time, the global carbon tax grows from 80\$/$tnCO_2$ in 2030 (in line with IEA, 2019) to about 350\$/$tnCO_2$ in 2050. In addition, the EU implements the Green Deal targets of GHG emission reduction of 55% in 2030 and net-zero transition by mid-century. The policy mix adopted to drive the EU energy system decarbonisation includes various instruments—e.g., strengthened EU ETS, subsidies insulation in buildings, accelerated expansion of renewable energy, ambitious technology standards, increased electrification of energy services, and uptake of innovative mitigation options (e.g., carbon capture storage, hydrogen, etc.).

Table 10. Scenario description

	Scenario Description	EU Climate target	Non-EU climate targets
REF	Reference scenario	Meets the EU NDC in 2030, no additional efforts after 2030	Meet their NDCs in 2030, policy ambition does not increase beyond 2030
DECARB	EU meets EGD Targets by 2030 & 2050, Global decarbonisation to 2°C	EU achieves 55/97% emissions reduction in 2030/ 2050 relative to 1990	Countries adopt ambitious universal carbon pricing to meet the 2°C target

3.4.4 Results on socio-economic and distributional effects

In the REF scenario, economic activity and emissions are found to gradually decouple by 2050 with emissions intensity of GDP declining in all countries, by about 2% annually over 2020-2050. This is a result of the accelerated uptake of renewable energy and low-carbon technologies, the more efficient use of energy resources, fuel switching, and stricter environmental regulations. As we aim to analyse the distributional impacts of climate policies, the disaggregated household-related projections by income decile should be constructed to ensure consistency with the national-level GEM-E3-FIT outputs—here, for Greece. The projections for income deciles are based on the income level and source, occupation, consumption patterns, and savings, through empirically estimated relations to disaggregate household energy demand by income decile.

In Greece, the recent evolution of income distribution among deciles shows limited changes in the last decade

Funded by the European Union

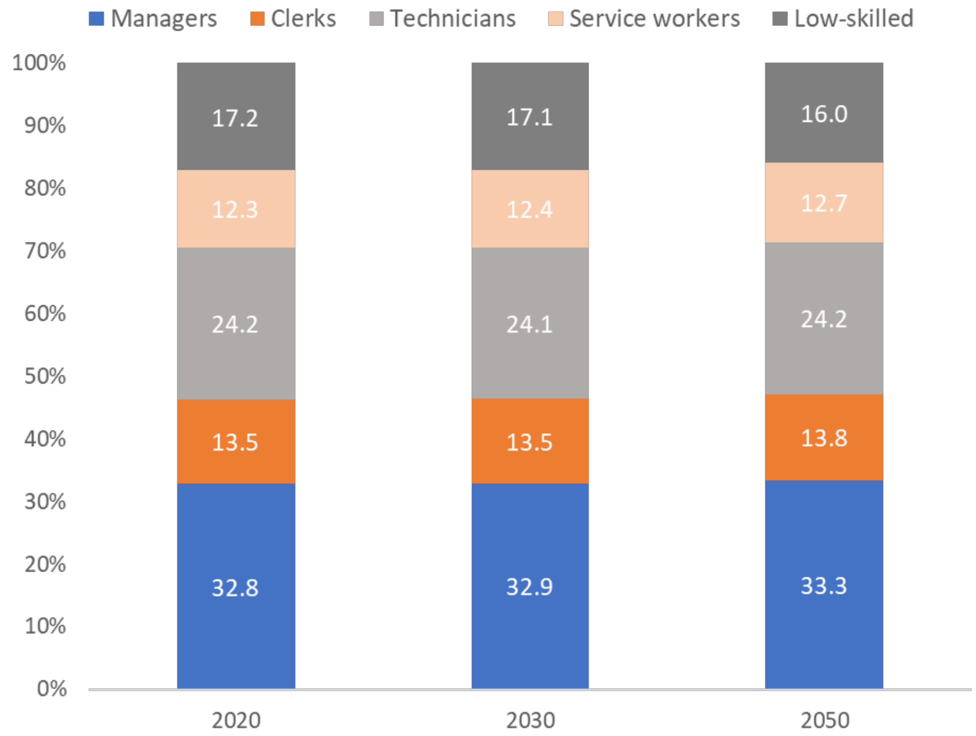
with small variations in the income shares of the bottom and top income quintiles. As there are large differences in earnings of different occupation types, the income distribution in the study is modelled via wage evolution of different occupation types and their respective distribution across deciles depending on sectoral evolution and labour intensity of the economy. According to OECD (2006), savings are highly concentrated in the top of the income distribution and saving rates increase with income. Over time, saving rates by decile as a percentage of disposable income do not vary largely (Eurostat, 2019) and can be assumed as constant in the REF scenario by 2050. The disaggregation of GEM-E3-FIT output into income deciles requires additional assumptions:

- Within decile, the income distribution is assumed constant over time
- The equivalised household size is assumed constant
- Consumption patterns and tax rates by decile are assumed constant over time
- Distribution of personal and household benefits and allowances from government by deciles is assumed constant over time

Technical progress, ageing population, changes in consumer behaviour, consumption patterns, industrial competitiveness, and policies shape the structure of socioeconomic developments in Greece. Changes in income distribution in the country are largely driven by GDP growth, labour supply and demand, technical progress, sectoral growth, wage differentials across skills, the distribution of skills, capital earnings, and transfers across deciles. The composition of value added differs significantly across sectors indicating that policies can have different distributional effects across countries. Income inequality is mostly influenced by inequality in labour skills and wages (Keeley,2015; Harrison et al., 2011). In the model, each household receives a share of the total wage income, based on the distribution of income by decile for each skill. The wage income from low-skilled occupations and service workers is more equally spread across different deciles, while income from high-skilled occupations (e.g., managers, technicians) and dividends is mostly directed to higher income deciles in Greece. In contrast, low-income households receive most of social benefits and other allowances. Economic development in the REF scenario involves a gradual transition towards a more service-oriented, technology-rich economy, resulting in a slight redirection of labour demand towards higher skills. Over 2020-2050 there is a slight decline in the value-added share generated by low skilled occupations (e.g., agricultural jobs) and an increase in the share of higher skilled jobs (e.g., managers). The change in occupations and labour skills has direct impacts on the distribution of income (Figure 11). As demand for high skills grows, a higher share of total wages would be directed towards higher deciles. Low-income groups receive income mainly from low-skill occupations, and thus their income is negatively affected. However, low-income deciles are dependent on government benefits and allowances, while higher deciles receive income mostly from labour and capital endowments.

Funded by
the European Union

Figure 11. Composition of Greek labour value added by skill in the REF scenario

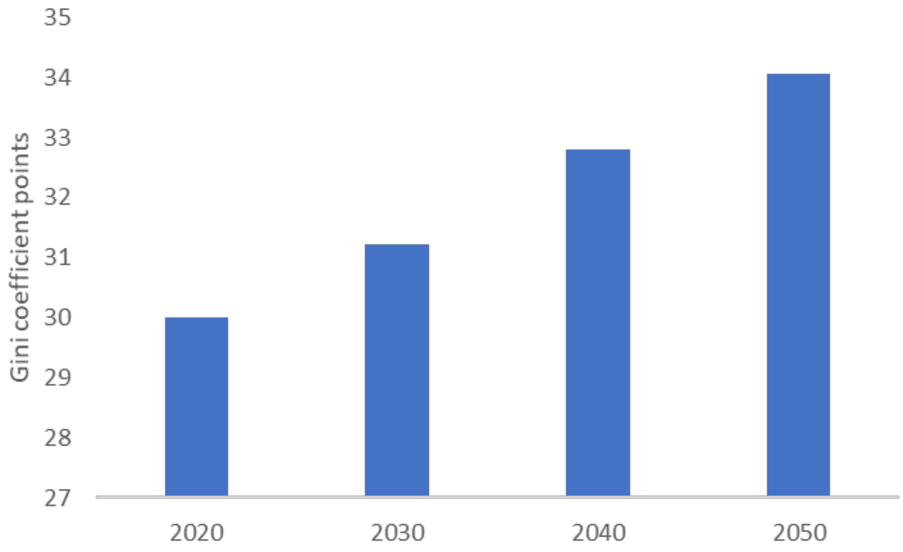


The transition towards a high-skilled and capital-intensive Greek economy results in increasing income inequality in the REF scenario as indicated by the Gini coefficient and the S80/S20 index. The inequality indicators strongly depend on the assumption of constant distribution of occupations across deciles, which faces limitations as it does not consider the impacts of potential labour supply adjustments induced by the transition to high skills, which may change skill distributions across the deciles.

The REF scenario dynamics result in limited increase in the Gini coefficient in Greece from 2020 levels (30.5%) by 0.7 percentage points (pp) in 2030 (31.2%); however, in the longer term, increased automation, digitisation, and higher requirements for labour skills drive a larger increase in income inequality, with the Gini coefficient increasing to 33.8 in 2050 (Figure 12). Greece is expected to remain close to the EU average in terms of the Gini coefficient until 2050 (the EU Gini coefficient is projected to slightly increase from 30% in 2020 to 32.8% in 2050). The S80/S20 indicator is projected to increase over time in the REF scenario, from 5.2 in 2020 to 5.45 in 2030, and further to 6.1 in 2050.

Funded by
the European Union

Figure 12. Evolution of the Gini coefficient in Greece in the REF scenario



The implementation of ambitious climate policies towards the long-term climate neutrality target (DECARB scenario) would have large-scale impacts triggered by the accelerated uptake of renewable energy and energy efficiency, the massive electrification of end-uses and the deployment of CCS and green hydrogen. The imposition of high carbon pricing drives energy system transformation towards a more capital-intensive structure, with increased investment to renewable energy, electric vehicles, and energy efficiency projects, leading to increases in CAPEX and a drop in OPEX and energy purchasing costs. As GEM-E3-FIT assumes optimal use of available capital resources in the REF scenario, reallocation of investments towards low-carbon, energy efficient technologies in the DECARB scenario leads to the so-called "crowding-out effect", as firms and households finance their clean energy investment by spending less on other commodities and investment purposes. High carbon prices increase the cost of energy services for firms and households and, hence, production costs throughout the economy, with a depressing effect on consumption and GDP; this is partly alleviated by increased investment in low-carbon technologies. Overall, the net-zero transition is projected to lead to a slowdown of EU economic growth by 0.3% in 2030 and 1.1% in 2050 compared to the REF levels with differential impacts across countries, depending on their economic structure, their relative position in international trade (especially for fossil fuels and low-carbon technologies), and the mitigation effort. The DECARB scenario impacts differently specific sectors in Greece, with sectors directly related to fossil fuels (e.g., mining, refineries, and fossil-based power plants) facing pronounced negative effects due to the shift towards low-carbon energy sources. In contrast, increased electrification of energy services drives increased activity in the electricity sector, required for electric vehicles and heat pumps, and the emergence of green hydrogen after 2035. The output of energy-intensive industrial sectors declines by about 2% with regard to the REF scenario, due to their carbon-intensive structure, as energy costs represent a high share of production costs. Energy efficiency improvements imply increased requirements for construction directed to building retrofits and thermal insulation.

The employment impacts of DECARB are relatively limited and are driven by declining GDP counterbalanced by the uptake of more labour-intensive technologies—e.g., renewable energy and energy efficiency (Fragkos and Paroussos, 2018). This aggregate effect masks large differences across productive activities, with some sectors facing extensive job losses (e.g., lignite mining, refineries) due to reduced output, while others are influenced positively by the transition (e.g., electricity, construction). These employment shifts across sectors require extensive re-allocation of workforce and the development of labour skills related to decarbonisation. The labour

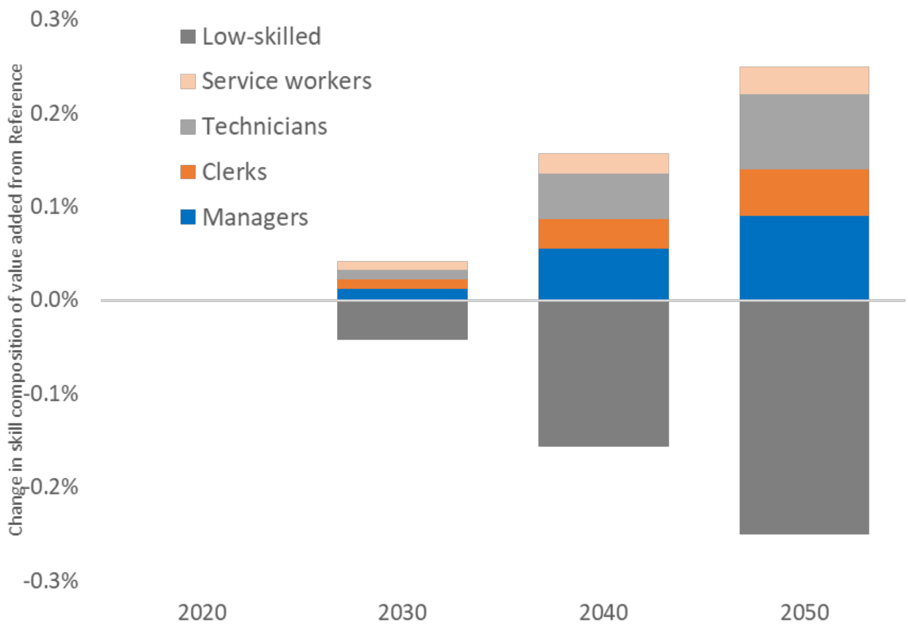
Funded by
the European Union

markets will be influenced by the transition, not only in activities directly linked to the transition, but also for workers at various levels of the supply chain or in sectors that observe a knock-on impact through multiplier effects (construction, agriculture).

The DECARB scenario would have a depressing effect in the Greek economy with GDP projected to decline by about 1% in 2050 compared to REF levels. Private consumption and employment are also negatively impacted. Higher unemployment levels would negatively influence average wage rates, with total income reducing by 0.4% in 2030 and 1.5% in 2050. The largest impacts are felt in low-income deciles, with the income of the lowest decile dropping by 2% from REF levels in 2050, while impacts are limited (less than 1%) in high-income groups; overall, we project a slightly increasing income inequality in Greece. This implies a slight increase in Gini coefficient from 33.8 in REF to 34.2 in DECARB in 2050.

The net-zero transition would also impact the composition of the Greek value added with increased share of high-skilled occupations to the detriment of low-skilled ones, due to higher demand for high-skilled labour required for the transition and the wage differential across different occupations and skills (as increased demand for managers results in a relatively higher increase in their respective share in income). The skills transition entails replacement of labour-intensive and low-skill occupations (Figure 13), such as lignite mining, by skill-intensive occupations for the design, manufacturing, development, and installation of clean technologies and innovative low-carbon products—these include manufacturing and software engineers, project designers, land development advisors, and other high-skilled professional or managerial positions (Fragkos et al., 2021).

Figure 13. Changes in the composition of value added by skill in Greece in DECARB compared to REF



3.4.5 Results on energy poverty

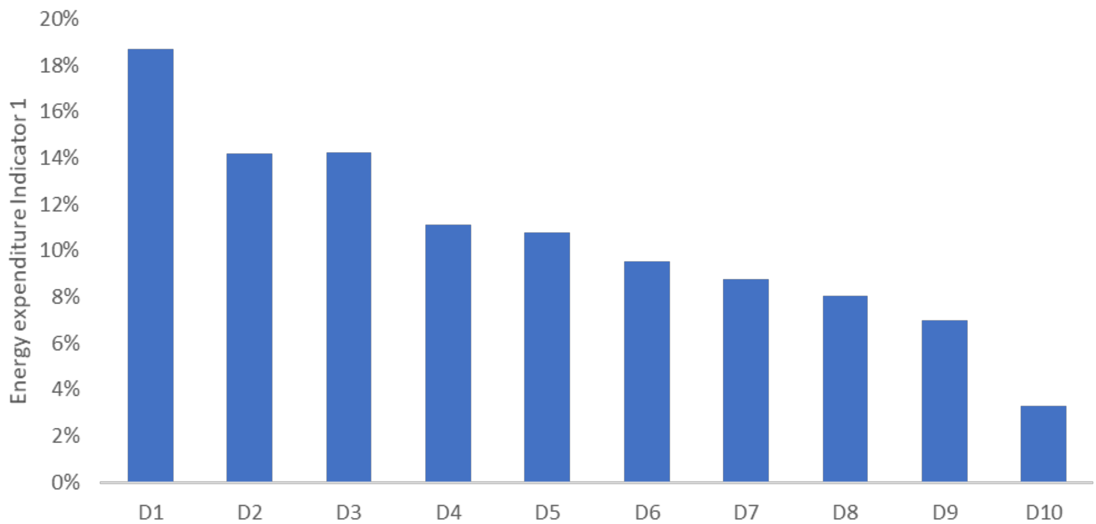
The deep energy system transformation towards net-zero requires large-scale investment by households targeted to the renovation of buildings and the purchase of energy-efficient equipment and low-carbon technologies, which are capital-intensive and increase CAPEX, thereby posing challenges for low-income classes. The latter cannot

Funded by the European Union

afford energy-efficient appliances, houses, and cars, which fuels the threat of energy poverty. Energy affordability is affected by how income inequality changes due to decarbonisation, as the amount of disposable income available for energy-related expenditure is impacted. The energy expenditure indicators (introduced in the previous section) are quantified using GEM-E3-FIT results combined with data on expenditure for fuels, electricity, and energy equipment from PRIMES-Buimo (Fotiou et al., 2022).

The share of energy expenditure in income differs across income deciles, indicating the different levels of vulnerability to changes in energy prices, with lower-income deciles having the highest vulnerability. The share of energy expenditure to income (Indicator 1) is estimated at 19% in 2020 for the lowest decile in Greece but is only 3% for the high-income deciles (Figure 14). When also considering the expenditure for energy equipment (including appliances, heating devices, cars, transport equipment), the share of energy expenditure (Indicator 2) increases by an average of 5.5 pp, ranging from 8% to 22% across income deciles. The increases are relatively higher in high-income deciles that commonly purchase more expensive equipment, highly efficient appliances, and more luxurious cars relative to low-income groups.

Figure 14. Energy expenditure Indicator 1 by income decile in Greece in 2020.



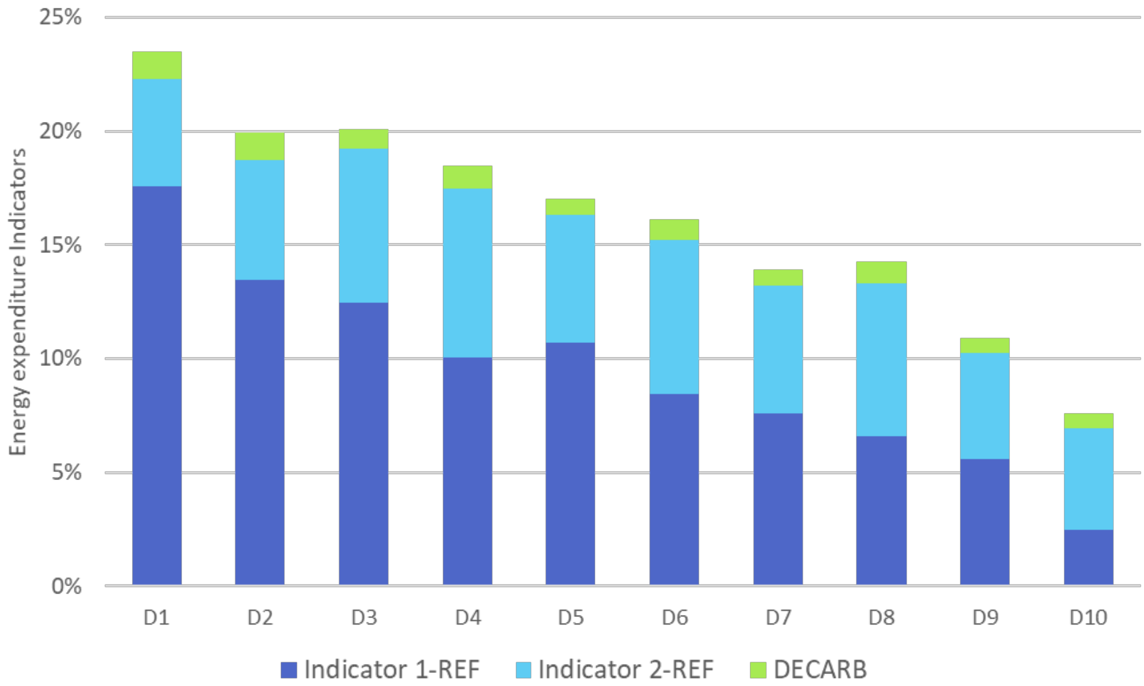
In the REF scenario, the share of energy expenditure to income declines somewhat in the longer term across income deciles, as household incomes increase faster than energy consumption and energy prices. The same trend is also evident when expenditure for energy and transport equipment is considered as well (Indicator 2), with this indicator dropping by about 1%-2% across income groups.

Decarbonisation entails substantial changes for household energy-related expenditure, along with the subsequent income distributional changes described above. Strong carbon pricing, increased prices for energy products, and the need to purchase more expensive low-carbon and efficient equipment result in increased energy expenditure across income deciles. The Energy Expenditure Indicator 1 increases by about 0.2-0.8 pp from REF in 2050, driven by increased energy-related expenditure and slight reduction in household income. The highest increases are found in low-income classes, indicating additional challenges to purchase energy and mobility services leading to higher threats for energy poverty increase. Higher increases are calculated based on the Energy Expenditure

Funded by
the European Union

Indicator 2 that includes the increased costs to purchase advanced energy-efficient equipment and low-emission cars. The highest increase is projected for low-income deciles (Figure 15).

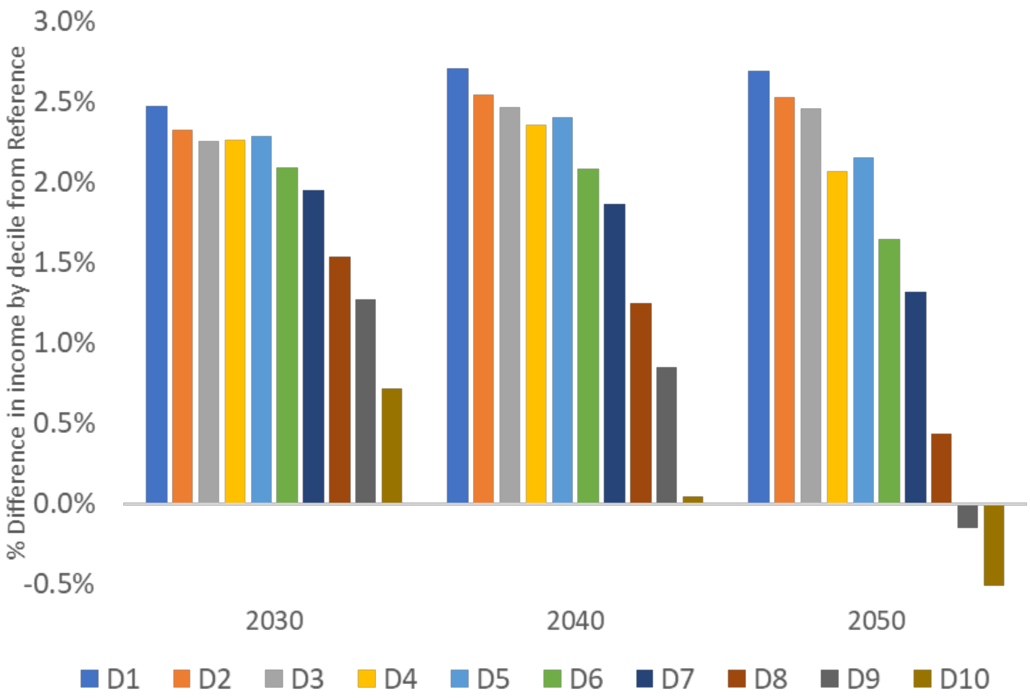
Figure 15. Energy expenditure Indicators in Greece for each income decile in 2050 in DECARB scenario.



The reduced income and increased energy expenditure would have larger impacts for low-income groups, increasing their vulnerability to energy poverty. Several measures are discussed to alleviate such risks and pave the way for a just transition, most of them based on different ways to use carbon revenues (Budolfsonet al., 2021). Here, we quantitatively assess the distributional impacts of directing the carbon revenues via lump-sum to households and via reduced social security contributions (DECARB_EQ), instead of recycling them through the public budget. The distribution of lump-sum transfers to different income groups follows the distribution of social benefits and allowances. The additional carbon revenues amount to about 1%-1.5% of GDP and thus the redirection of carbon revenues has an important effect on income inequality. The available income of Greek households increases by more than 1% from REF levels, but this is moderated by the macroeconomic impacts of the transition in the longer run. Increased government benefits have large positive impacts for lower-income deciles that largely depend on these benefits and allowances (their incomes increase by close to 2.5% from Reference), while the impacts are lower for high-income households and even turn negative in 2050, due to the reduced economic activity with GDP declining relative to the REF scenario. This leads to reduced income inequalities, as reflected in a reduction of the Gini coefficient, induced using carbon revenues as lump-sum transfers that mostly benefit lower-income households. This measure counterbalances the regressive impacts of the skills transition and reduces income inequality with the Gini coefficient in Greece declining by 0.8 pp and 1.4 pp in 2030 and 2050, respectively, relative to REF, with similar trends observed also in the S80/S20 index.

Funded by
the European Union

Figure 16. Change in total income per decile group in DECARB_EQ scenario relative to REF over 2030-2050



3.5 Conclusions

Decarbonisation efforts can result in large-scale economic restructuring with potential regressive distributional impacts, disproportionately affecting disadvantaged population groups. The imposition of additional carbon taxes on energy products and the need to purchase energy efficient albeit more expensive equipment may negatively affect low-income households that face funding scarcity while increasing the threat of energy poverty. Environmental policies are commonly associated, in literature, with regressive distributional impacts that negatively affect low-income households. Ignoring such distributional effects can result in less effective policies and increased social inequalities. Well-designed strategies and policies are required to achieve progressive outcomes by considering appropriate compensation schemes, either by increasing household income through lump-sum payments, reducing other taxes, or through the social security system.

After studying the EU and national policy context, the challenges to quantifying energy poverty, and the relevant policies in place in Greece, the GEM-E3-FIT model—expanded to represent ten income deciles by differentiating their income sources, savings, and consumption patterns—is used to quantify the socioeconomic and distributional impacts of the transition to net zero by 2050. Decarbonisation affects employment and labour income, leading to a reduction in low-skilled labour demand combined with an increase in high-skilled jobs required for the transition. This causes negative distributional impacts through the labour market leading to higher social inequality levels. The net-zero transition can also increase the energy-related expenditure in households, especially in low-income groups, raising the issues of energy poverty and energy affordability, since these income classes already spend a large share of their income to purchase energy services and equipment.

Overall, the model-based analysis shows that decarbonisation increases modestly existing inequality across income classes, with low-income households facing more negative effects than higher-income ones. However, using carbon revenues as lump-sum transfers to households and requiring reduced social security contributions has clear benefits. These include increasing total employment while significantly reducing the inequality across

Funded by
the European Union

income classes. Since we assume that the distribution of lump-sum transfers follows the distribution of social benefits and allowances to income groups, the redistribution of carbon revenues will significantly reduce income inequality bringing high benefits for low-income households.

We find that, if Greece — alongside other EU countries — adopts the necessary carbon tax and then returns revenues to citizens on an equal per capita basis, it will be possible to meet the net-zero target in 2050 while also reducing inequality. These results indicate that it is possible for a society to implement strong climate action without hampering goals for equity and development.

An important caveat of the analysis, to be addressed in planned future research, is the assumption that income distribution remains constant over time within deciles, which is rather simplistic. If additional data is provided and model running time is improved, the GEM-E3-FIT modelling framework can be further enhanced to represent income percentiles, thus improving its simulation properties, especially when it comes to assessing policy impacts for the most vulnerable income groups. In addition, the model-based analysis can be expanded to cover the recent increases in energy prices and the RePowerEU strategies that will highly impact the economic and distributional impacts of the transition to net zero in Greece and in the rest of EU countries.

Funded by
the European Union

4 MEDUSA - Modelling Equity and DistribUtional impacts for Socioeconomic Analysis

Addressing the major challenges of the 21st century, such as climate change, will require complex and ambitious policies that promote social justice. To do so, it is necessary to design efficient policies that do not exacerbate existing inequalities, such as income or gender inequality. In this sense, it is essential to carry out impact analyses of policies from a holistic perspective that evaluates the economy, energy, land and water systems in an integrated manner before implementing them.

While Integrated Assessment Models (IAMs), such as GCAM[28], have been a fundamental tool in climate-energy-economy modelling, micro-simulation models for distributional analysis have the advantage of providing more heterogeneous results that help to identify the socio-economic impacts of policies more robustly. These models make it possible to identify the households most affected by examined policies and to implement compensatory measures to make such policies fairer and avoid social rejection. Thus, the combination of both models (IAMs and microsimulation models) can provide valuable results for decision making.

MEDUSA is an R package that allows the development of distributional analyses in isolation or in connection with other models such as GCAM or other IAMs. Its extensive database allows for highly disaggregated results, considering numerous socio-economic and demographic characteristics of households, such as income level, place of residence, type of family or the degree of feminisation of the household. Currently, the prototype works for Spain, but the package could be extended to all countries, given the raw data of the model are available.

4.1 The household microsimulation model

MEDUSA allows to develop distributional analyses based in the following overnight effect microsimulation model. The model is built up with the microdata from the Household Budget Survey, a common statistic in all EU countries which is increasingly standardised, and which has relevant potential due the large amount of socioeconomic information that it collects. The HBS provides information about household final consumption expenditure on goods and services and information on some socioeconomic and demographic characteristics of each household. The HBS provides information at two levels: one for households and their expenditures and the other for household members.

In order to have a suitable database for the model, some adjustments are necessary. Firstly, some socio-economic variables have been renamed and new ones have been created based on the information collected in the survey (e.g., income variables: decile and quintile). In this sense, and since medusa aims to facilitate gender-sensitive analyses, the model includes two variables that allow capturing gender implications: the gender of the reference person of the household and the degree of feminisation of the household. Although the HBS already includes the gender of the reference person among its variables, the second indicator is calculated using the information on the gender of household members. Thus, we calculate the percentage of household members who are women over 14 years (this age is used because it is considered the age at which individuals begin to have decision-making capacity) and then we divide the households into 5 groups based on the share of women: 0-20% (lowest feminisation degree), 20%-40%, 40%-60%, 60%-80% and 80%-100% (highest feminisation degree). We adopt

[28] https://www.i2am-paris.eu/detailed_model_doc/gcam

Funded by the European Union

this approach proposed by Osorio et al., 2022 within the framework of household carbon footprints for capturing all the dimensions of the intra-household consumption behaviour. Secondly, it is common that expenditure variables by COICOP categories must be aggregated because it is often difficult to have price impacts at such a disaggregated level. To adjust the consumption expenditure data to the inputs provided by the price model, we include in the package a function that allows the aggregation of variables (the aggregation is determined by default but can also be customised according to the user's needs). Moreover, if the inputs of the price shock are determined by a macro model, an additional adjustment is necessary. In fact, even though the HBS covers a representative sample of the population and provides a very detailed image of the annual consumption of households, the aggregate costs of the survey are not aligned with the principles and data of the National Accounting, which builds its macroeconomic aggregates based on more complete sources of information. Therefore, before the simulation, the HBS data should be adjusted to make them consistent with the macroeconomic dimension. For this purpose, the package has a function that allows the survey to be elevated to make it consistent with the National Accounts. The following adjustments are made within the function: i) Scaling the HBS population to be consistent with the reference population of the National Accounts and ii) Scaling the HBS consumption data according to the final consumption per energy good of the National Accounts.

The model simulates the changes in spending in the COICOP categories, multiplying the changes in prices by the current levels of spending on the different products consumed by households that are part of the HBS dataset. Thus, the model reflects the direct impacts of the selected price shock before assuming any changes in behaviour related to the new prices. In other words, the microsimulation model does not reflect the reaction of the different types of households to the expected changes in prices. In order to carry out a "behavioural" impact study, it would be necessary to collect the direct reactions of consumers (through the price elasticities of demand for goods) and the induced reactions (through cross-elasticities and income elasticities). At the distributional level the lack of elasticities would not have a large effect because if the elasticity introduced is homogeneous for all households it will not affect the differences between different types of households. However, in future updates of the model it would be interesting to introduce heterogeneous household elasticities. Also, in the case of energy goods and transportation services, these effects are known to be small in the short and medium term, since households do not easily change their behaviour as far as energy consumption is concerned (Labandeira et al., 2017).

The results derived from the model are presented as the relative impact (%) on total equivalent consumption expenditure. The relative impact, Δe_h^s, shows the additional cost that household h would assume in a proposed scenario s in relative terms (in percentage), compared to the initial household expenditure, and it is calculated as:

$$\Delta e_h^s = \frac{\sum_c e_{c,h}(1+\Delta p_c^s) - \sum_c e_{c,h}}{\sum_c e_{c,h}} \times 100 \qquad \text{(E.3)}$$

here e_(c,h) refers to the total spending on each consumption category, c, consumed by each of the household, in the baseline scenario and Δp_c^s is the increase in prices by consumption category and scenario obtained with the price model.

The great granularity of the data contained in the HBS allows the integration of the intersectional approach in the analysis. The results can therefore be calculated according to numerous socioeconomic characteristics of the households (such as, class, gender, race…). Furthermore, to facilitate the analysis of the results, the package allows the generation of summary graphs of the distributional impacts either for one or several socio-economic

Funded by
the European Union

variables.

4.2 The R package

MEDUSA is a R package that allows equity and distributional analysis. The prototype will work for Spain soon, but in the short-medium term the idea is to extend it to all EU countries. In future updates the package could be also extended to all non-EU countries that are able to provide the raw data needed for the model. The package is composed of a main function (calc_di) that returns the distributional impacts of a given price shock and numerous auxiliary functions that provide the user different functionalities for using the package.

Functions to be used by the user

calc_di

Details: main function to calculate the distributional impacts for different price shocks and to save the results and the figures

```
calc_di(
  year,
  elevate = F,
  shocks,
  var_impact = "all",
  var_intersec = NULL,
  fig = T,
  save = T,
  file_name_impact = "D_impact",
  file_name_intersec = "DI_impact"
)
```

Arguments

year

year for the simulation. Available time series: 2006-2021

elevate

if TRUE elevate the HBS to national accounting. If FALSE (by default) do not elevate.

shocks

a dataset with the price shocks per coicop to be applied. The format of the dataset has to correspond to the

Funded by the European Union

predefined one in the package. To save a csv file with the right format to enter the price shocks run `ex_shocks()`. You can enter more scenarios by including more columns to the right (e.g. s3). A price shock greater than 1 indicates a price increase (e.g. 1.1 indicates a 10% increase) and less than 1 indicates a price decrease (e.g. 0.9 indicates a 10% decrease).

var_impact

variable(s) according to which you want to calculate distributional impacts. If "all" (by default) calculates the distributional impacts for each of the variables specified in the package. If not, you can indicate the variable on the basis of which you want to calculate the distributional impacts. If not, you can indicate a variable or a vector of variables to calculate distributional impacts. If you want to see the variables for which the calculation is available run `available_var_impact()`. If you do not want to calculate distributional impacts per variable indicate NULL.

var_intersec

set of variables (2) according to which you want to calculate the intersectional distributional impacts. If "all", it calculates the distributional impacts for each of the combinations of variables specified in the package. If not, you can indicate the set of variables according to which you want to calculate the intersectional distributional impacts. If you wish to see the set of variables for which the calculation is available, run `available_var_intersec()`. To enter a set of variables for the calculation, it must follow the same format as the output of `available_var_intersec()`, i.e. a table whose columns have category_a and category_b as their titles. If you do not want to calculate distributional impacts, indicate NULL (by default).

Save

if TRUE saves the dataframes with the results for the distributional impacts calculated by the function. If FALSE do not save.

file_name_impact

name of the file to save the results of basic distributional impacts, if save TRUE. By default "D_impacts".

file_name_intersec

name of the file to save the results of the intersectional distributional impacts, if save TRUE. By default "DI_impacts".

fig

if TRUE (by default) create and save the figures of the distributional impacts calculated by the function. If

Funded by the European Union

FALSE do not create neither save.

Value

a list containing the generated datasets summarising the basic or/and the intersectional distributional impacts per selected variable or set of variables.

ex_shocks

Details: function to save a csv file in which the change in prices must be introduced to apply a price shock. Save the file, introduce the price shocks and load in R. The COICOP variables of the file correspond to the aggregate variables of the package, if you are not going to aggregate the COICOP variables you have to replace the column labels by the COICOP variables that appear in your dataset.

```
ex_shocks()
```

Value

a csv file in which the change in prices must be introduced to apply a price shock

ex_var_intersec

Details: function to save a csv file in which the change in prices must be introduced to apply a price shock. Save the file, introduce the price shocks and load in R. The COICOP variables of the file correspond to the aggregate variables of the package, if you are not going to aggregate the COICOP variables you have to replace the column labels by the COICOP variables that appear in your dataset.

```
ex_var_intersec()
```

Value

a csv file with the set of variables for which the calculation of intersectional distributional impacts is available.

available_var_impact

Details: function that returns the variables for which the calculation of basic distributional impacts is available.

```
available_var_impact()
```


Funded by
the European Union

Value

variables for which the calculation of basic distributional impacts is available.

available_var_intersec

Details: function that returns the variables for which the calculation of intersectional distributional impacts is available.

```
available_var_intersec()
```

Value

set of variables for which the calculation of intersectional distributional impacts is available.

Internal package functions

load_rawhbs

Details: main function to load the Spanish Household Budget Survey (HBS)

```
load_rawhbs(year, path)
```

Arguments

year

year of the HBS you want to load

path

LOCAL path to the folder where the epf's are stored. Not included in the pkg.

Value

a list with the 3 files of the HBS

rename_values

Funded by
the European Union

Details: function to rename the codified values of the dataset to the meaningful values detailed in the mapping included in the package.

```
rename_values(data, current_var)
```

Arguments

data

dataset to be standardized

current_var

column name to be standardized

Value

a dataset with labels renamed based in the mapping included in the package.

standardize

Details: function to standarize data names

```
standardize(data)
```

Arguments

data

dataset to be standardized

Value

a dataset with the variables and labels renamed based in the mapping included in the package.

add_coicop

Details: function to add COICOP categories in the Spanish Household Budget Survey (HBS) according to the aggregation (coicop_year) specified in the package.

```
add_coicop(data, year)
```

Arguments

data

a data frame containing the microdata of the HBS

year

year of the HBS you want to use

Value

a dataset with HBS data where COICOP categories are aggregated according to the classification specified in the package

elevate_hbs

Details: function to elevate the Spanish Household Budget Survey (HBS) to national accounting.

```
elevate_hbs(data, year, country = "ES")
```

Arguments

data

dataset with the data from the HBS

year

year of the HBS you want to elevate to national accounting

country

country of the HBS you want to elevate. By default "ES" (for the moment it only works for Spain, so DO NOT TOUCH)

Value

a dataset with the HBS data where expenses are elevated to national accounting

price_shock

Funded by the European Union

Details: function to apply a specific price shock to the different COICOP categories of the Household Budget Survey (HBS).

```
price_shock(data, shocks, year)
```

Arguments

data

input data from the HBS to apply the price shocks.

shocks

a dataset with the price shocks per coicop to be applied. The format of the dataset has to correspond to the predefined one in the package. To save a csv file with the right format to enter the price shocks run `ex_shocks()`. You can enter more scenarios by including more columns to the right (e.g. s3). A price shock greater than 1 indicates a price increase (e.g. 1.1 indicates a 10% increase) and less than 1 indicates a price decrease (e.g. 0.9 indicates a 10% decrease).

year

base year for the simulation. It must be the same as the year of the HBS.

Value

a dataset with the HBS data and the new expenses for COICOP categories after the application of the price shock.

impact

Details: function to calculate the distributional impacts based in one or more socioeconomic or demographic variables (one impact per variable).

```
impact(data, var = categories$categories, fig = T)
```

Arguments

data

a dataset with the input data needed to calculate distributional impacts. The dataset should contain both the household expenditures collected in the HBS and the expenditures after applying the price shock.

var

variable(s) according to which you want to calculate distributional impacts. If categories$categories (by default) calculates the distributional impacts for each of the variables specified in the package. If not, you can indicate a variable or a vector of variables to calculate distributional impacts.If you want to see the variables for which the calculation is available run `available_var_impact()`.

save

If TRUE (by default) saves a list of the generated datasets (.RData) summarising the distributional impacts per selected variable. If FALSE do not save.

file_name

name of the file to save the results, if save TRUE. By default "D_impacts".

fig

generates and saves a graph that summarises the distributional impacts. By default it is TRUE, for the graph/s not to be generated and saved indicate FALSE.

Value

a list containing the generated datasets (.RData) summarising the distributional impacts per selected variable.

impact_intersectional

Details: function to calculate the distributional impacts based in the intersection of two socioeconomic or demographic variables (2 variables per impact).

```
impact_intersectional(data, pairs = is_categories,  save = T,  file_name = "DI_impact",  fig = T)
```

Arguments

data

a dataset with the input data needed to calculate the intersectional distributional impacts. The dataset should contain both the household expenditures collected in the HBS and the expenditures after applying the price shock.

pairs

Funded by
the European Union

set of variables (2) according to which you want to calculate distributional impacts. If is_categories (by default) calculates the intersectional distributional impacts for each of the set of variables specified in the package. If not, you can indicate the set of variables according to which you want to calculate the intersectional distributional impacts.If you want to see the set of variables for which the calculation is available run `available_var_intersec()`. To enter a set of variables for the calculation, it must follow the same format as the output of `available_var_intersec()`, i.e. a table whose columns have category_a and category_b as their titles.

save

If TRUE (by default) saves a list of the generated datasets (.RData) summarising the intersectional distributional impacts per selected set of variable. If FALSE do not save.

file_name

name of the file to save the results, if save TRUE. By default "DI_impacts".

fig

generates and saves a graph that summarises the intersectional distributional impacts. By default it is TRUE, for the graph/s not to be generated and saved indicate FALSE.

Value

a list containing the generated datasets (.RData) summarising the intersectional distributional impacts per selected set of variables.

basic_graph

Details: function to create a basic graph to summarise the distributional impact based in one or more socioeconomic or demographic variable (one plot per variable) (INTERNAL FUNCTION).

```
basic_graph(data, var = categories$categories)
```

Arguments

data

a dataset with the input data needed to generate a basic graph.

var

Funded by the European Union

variable(s) according to which you want to generate the graph. If categories$categories (by default) creates a graph with the distributional impacts for each of the variables specified in the package. If not, you can indicate a variable or a vector of variables to crate the graph.If you want to see the variables for which the function is available run `available_var_impact()`.

Value

a graph per selected variable/s summarizing distributional impacts.

intersectional_graph

Details: function to create an intersectional graph to summarise the distributional impact based in the intersection of two socioeconomic or demographic variables (2 variables per plot).

```
intersectional_graph(data, pairs = is_categories)
```

Arguments

data

a dataset with the input data needed to generate the intersectional graph.

pairs

set of variables (2) according to which you want to create the intersectional graph. If is_categories (by default), it generates the intersectional graph for each of the combinations of variables specified in the package. If not, you can indicate the set of variables according to which you want to generste the intersectional graph. If you wish to see the set of variables for which the calculation is available, run `available_var_intersec()`. To enter a set of variables for the calculation, it must follow the same format as the output of `available_var_intersec()`, i.e. a table whose columns have category_a and category_b as their titles.

Value

a graph per selected set of variables summarizing the distributional impacts.

adjust_wh

Details: function to adjust the width and height of a basic graph depending on the number of scenarios and labels.

```
adjust_wh(data, var_w, var_h)
```

Arguments

Funded by
the European Union

data

a dataset used to create a basic graph.

var_w

variable on which the width of the basic graph depends.

var_h

variable on which the height of the basic graph depends.

Value

a list containing the width and the height of the basic graph to be created.

adjust_wh_is

Details: function to adjust the width and height of a intersectional graph depending on the number of scenarios and labels.

```
adjust_wh_is(data, var_w, var_h)
```

Arguments

data

a dataset used to create a basic graph.

var_w

variable on which the width of the basic graph depends.

var_h

variable on which the height of the basic graph depends.

Value

a list containing the width and the height of the intersectional graph to be created.

Funded by
the European Union

4.3 Conclusions and further research

MEDUSA is a R package that allows equity and distributional analysis, which first version will be published soon. It is based in an overnight effect microsimulation model which is based in the microdata of the HBS. The model simulates the changes in spending in the COICOP categories, multiplying the changes in prices by the current levels of spending on the different products consumed by households. Thus, the model reflects the direct impacts of the selected price shock before assuming any changes in behaviour related to the new prices.

The results derived from the model are presented as the relative impact (%) on total equivalent consumption expenditure (see E.3). And one of the advantages of the model is that the great granularity of the data contained in the HBS allows the results to be calculated according to numerous socioeconomic characteristics of the households, including the gender of the reference person in the household and the degree of feminisation of the household, which would allow more gender-sensitive analysis.

We have also identified some lines of work to make medusa more useful and increase its functionalities. In this sense, within the package it would be interesting to introduce new functions that allow us to calculate the distributional impacts in monetary units, to calculate Consumer Price Indices according to the socioeconomic characteristics of households (through the Laspeyres-type Consumer Price Index) or to calculate indicators of energy or transport poverty. These new functions will provide a better understanding of the dynamics of the energy transition in relation to the prices faced by the various economic groups, their corresponding consumption needs and the evolution of energy poverty. In the short to medium term, we also plan to extend the package so that it works for all EU Member States and in the longer term it could be extended to non-EU countries that have suitable databases for the model. As far as the model is concerned, the possibility of introducing behaviour by using heterogeneous elasticities for different goods/services and household types could be explored. Finally, further work should be done in the area of results visualisation.

Funded by
the European Union

5 References

Alber, G. (2009). Gender and Climate Change Policy. *Population Dynamics and Climate Change*.

Allwood, G. (2014). *Gender Mainstreaming and EU Climate Change Policy* (SSRN Scholarly Paper 2523417). https://papers.ssrn.com/abstract=2523417

Allwood, G. (2020). Mainstreaming Gender and Climate Change to Achieve a Just Transition to a Climate-Neutral Europe. *JCMS: Journal of Common Market Studies*, *58*(S1), 173–186. https://doi.org/10.1111/jcms.13082

Alonso-Epelde, E., Garcia-Muros, X., & Gonzalez-Eguino, M. (Under Review). *Impact assessment of climate policies on inequality from a gender perspective: A systematic literature review*.

Antepara, I., Papada, L., Gouveia, J.P., Katsoulakos, N., & Kaliampakos, D. (2020) Improving energy poverty measurement in southern European regions through equivalization of modeled energy costs. Sustainability, 12(14), 5721.

Arsenopoulos, A., Marinakis, V., Koasidis K., Stavrakaki, A., & Psarras, J. (2020) Assessing resilience to energy poverty in Europe through a multi-criteria analysis framework. Sustainability, 12(12), 4899.

Baker, K. J., Mould, R., & Restrick, S. (2018). Rethink fuel poverty as a complex problem. *Nature Energy*, *3*(8), Article 8. https://doi.org/10.1038/s41560-018-0204-2

Balasko, Y., & Tourinho, O.A. (2014) Factor proportionality in multiple households closed CGE models: theory and illustrations. Economic Theory Bulletin, 2014, vol. 2, issue 2, 119-136.

Bersisa, M. (2019) Multidimensional measure of household energy poverty and its determinants in Ethiopia 1. In Economic Transformation for Poverty Reduction in Africa (pp. 58-83). Routledge.

Boardman, B. (1991) Fuel Poverty: From Cold Homes to Affordable Warmth. Belhaven Press, London

Bourguignon, F., & Spadaro, A. (2006). Microsimulation as a tool for evaluating redistribution policies. *The Journal of Economic Inequality*, *4*(1), 77–106. https://doi.org/10.1007/s10888-005-9012-6

Bouzarovski, S., Thomson, H., Cornelis, M., Varo, A. & Guyet, R. (2015) Towards an inclusive energy transition in the European Union: Bouzarovski, S., & Petrova, S. (2015). A global perspective on domestic energy deprivation: Overcoming the energy poverty–fuel poverty binary. Energy Research & Social Science, 10, 31–40. https://doi.org/10.1016/j.erss.2015.06.007

Bouzarovski, S., Thomson, H., Cornelis, M., Varo, A. & Guyet, R. (2020) Towards an inclusive energy transition in the European Union: Confronting energy poverty amidst a global crisis. EU Energy Poverty Observatory, Luxembourg, 2020.

Bubbico, L., & Freytag, L. (2018) Inequality in Europe. (online) European Investment Bank (EIB). Available at: http://www.eib.org/attachments/efs/econ_inequality_in_europe_en.pdf.

Budolfson, M., Dennig, F., Errickson, F., Feindt, S., Ferranna, M., Fleurbaey, M., Klenert, D., Kornek, U., Kuruc, K., Méjean, A., & Peng, W. (2021) Protecting the poor with a carbon tax and equal per capita dividend. Nature Climate Change, 11(12), 1025-1026.

Cagetti, M., & De Nardi, M. (2008) Wealth inequality: Data and models. Macroeconomic Dynamics, 12(S2), 285-313.

Cho, S., Crenshaw, K. W., & McCall, L. (2013). Toward a Field of Intersectionality Studies: Theory, Applications, and Praxis. Signs: Journal of Women in Culture and Society, 38(4), 785–810. https://doi.org/10.1086/669608

Cockburn, J. (2001) Trade liberalisation and poverty in Nepal: A CGE micro simulation analysis.

CPB (2011) The labour market in CGE models.

Crenshaw, K. (1991). Mapping the Margins: Intersectionality, Identity Politics, and Violence against Women of

Funded by the European Union

Color. Stanford Law Review, 43(6), 1241–1299. https://doi.org/10.2307/1229039

Crentsil, A.O., Asuman, D., & Fenny, A.P. (2019) Assessing the determinants and drivers of multidimensional energy poverty in Ghana. Energy Policy, 133, 110884.

De Maio, F.G. (2007) Income inequality measures. Journal of Epidemiology & Community Health, 61(10), 849-852.

Delugas, E. & Brau, R. (2018) Subjective Well-Being and Energy Poverty: new insights from the combination of objective and subjective. Mimeo.

Djoudi, H., Locatelli, B., Vaast, C., Asher, K., Brockhaus, M., & Basnett Sijapati, B. (2016). Beyond dichotomies: Gender and intersecting inequalities in climate change studies. Ambio, 45(3), 248–262. https://doi.org/10.1007/s13280-016-0825-2

Dobbins, A., Fuso Nerini, F., Deane, P., & Pye, S. (2019). Strengthening the EU response to energy poverty. Nature Energy, 4(1), Article 1. https://doi.org/10.1038/s41560-018-0316-8

EC (2017) European Semester Thematic Factsheet: Addressing Inequalities. (Online) EC. Available at: https://ec.europa.eu/info/sites/info/files/file_import/european-semester_thematic-factsheet_addressing-inequalities_en_0.pdf

EC (2018) Ageing Report.

EC (2018) The EU-wide income distribution: inequality levels and decompositions

EC (2019) Clean energy for all Europeans package, https://energy.ec.europa.eu/topics/energy-strategy/clean-energy-all-europeans-package_en

E3Modelling, 2017, GEM-E3 Model Manual, Available at: https://e3modelling.com/modelling-tools/gem-e3/

Energy communities Law of 2018, Law 4513/2018, FEK 9/A/23.01.2018

European Commission. (2018). Communication from *the commission to the European parliament, the European council, the council, the European economic and social committee, the committee of the regions and the European investment bank. A Clean Planet for all A European strategic long-term vision for a prosperous, modern, competitive and climate neutral economy. COM (2018) 773 final*.

European Commission. (2019). *Communication on the European green deal, COM(2019)640 final.*

European Commission. (2020). *Stepping up Europe's 2030 climate ambition Investing in a climate-neutral future for the benefit of our people. COM (2020) 562 final.*

European Commission. (2021). *Proposal for a COUNCIL DIRECTIVE. Restructuring the Union framework for the taxation of energy products and electricity (recast). COM (2021) 563 final*.

European Commission. (2023). *DG energy, Oil Bulletin https://data.europa.eu/data/datasets/eu-oil-bulletin?locale=sv*.

European Parliament. (2012a). *European Parliament resolution of 11 September 2012 on the role of wom¬en in the green economy. Https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52012IP0321*.

European Parliament. (2012b). *European Parliament resolution of 20 April 2012 on women and climate change. Https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52012IP0145*.

European Parliament. (2012c). *Report prepared for the European Parliament Committee on Women's Rights and Gender Equality by Nicole Kiil-Nielson in 2012, which resulted in a motion of the European Parliament that was adopted on 9 March 2012 (A7-004912012).*

Eurostat (2019) Eurostat Statistic Explained: People at Risk of Poverty or Social Exclusion. Edition 2018. (Online) Retrieved from: https://ec.europa.eu/eurostat/

Eurostat. (2021). *Household Budget Surveys (HBS)*. https://ec.europa.eu/eurostat/web/household-budget-surveys

Eurostat. (2023a). *Electricity prices components for household consumers – annual data (band DC). Https://ec.europa.eu/eurostat/databrowser/view/NRG_PC_204_C__custom_1966175/default/table?lang=en*.

Funded by
the European Union

Eurostat. (2023b). *Gas prices components for household consumers – annual data (band D2) https://ec.europa.eu/eurostat/databrowser/view/nrg_pc_203_c/default/table?lang=en*.

Faiella, I., & Lavecchia, L. (2021) Energy poverty. How can you fight it, if you can't measure it?. Energy and Buildings, 233, 110692.

Feenstra, M., & Özerol, G. (2021). Energy justice as a search light for gender-energy nexus: Towards a conceptual framework. *Renewable and Sustainable Energy Reviews*, *138*, 110668. https://doi.org/10.1016/j.rser.2020.110668

Flues, F., & Thomas, A. (2015). *The distributional effects of energy taxes*. OECD. https://doi.org/10.1787/5js1qwkqqrbv-en

Fotiou, T., Capros, P., & Fragkos, P. (2022) Policy Modelling for Ambitious Energy Efficiency Investment in the EU Residential Buildings. Energies, 15(6), 2233.

Fragkos, P., Fragkiadakis, K., Sovacool, B., Paroussos, L., Vrontisi, Z., & Charalampidis, I. (2021) Equity implications of climate policy: Assessing the social and distributional impacts of emission reduction targets in the European Union. Energy, 237, 121591.

Fragkos, P., & Paroussos, L. (2018) Employment creation in EU related to renewables expansion Appl. Energy 230 935–45

Furceri, D., & Loungani, P. (2013) Who let the gini out? Finance & Development, 50(4), 25-27.

Goodman, A., & Oldfield, Z. (2004). *Permanent differences? Income and expenditure inequality in the 1990s and 2000s* (Research Report R66). IFS Report. https://doi.org/10.1920/re.ifs.2004.0066

Gouveia, J.P., Palma, P., & Simoes, S.G. (2019) Energy poverty vulnerability index: A multidimensional tool to identify hotspots for local action. Energy Reports, 5, 187-201.

Harrison, A., McLaren, J., & McMillan, M. (2011) "Recent perspectives on trade and inequality", Annual Review of Economics, 3: 261–289

Haughton, J., & Khandker, S. (2009) Inequality measures. Handbook on poverty and inequality. Washington, DC: The World Bank, 101Á20.

Healy, J.D., Clinch J.P. (2002) Fuel poverty, thermal comfort and occupancy: results of a national household-survey in Ireland. Applied Energy, 73(3-4), 329-343.

Hills, J. (2012) Getting the measure of fuel poverty: Final Report of the Fuel Poverty Review.

IEA (2019) World Energy Outlook, International Energy Agency, Paris

IMF (2015) Causes and Consequences of Income Inequality: A Global Perspective. (Online) IMF. Available at https://www.imf.org/external/pubs/ft/sdn/2015/sdn1513.pdf

IPCC. (2022). *Climate Change 2022: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [H.-O. Pörtner, D.C. Roberts, M. Tignor, E.S. Poloczanska, K. Mintenbeck, A. Alegría, M. Craig, S. Langsdorf, S. Löschke, V. Möller, A. Okem, B. Rama (eds.)]. Cambridge University Press. Cambridge University Press, Cambridge, UK and New York, NY, USA, 3056 pp., doi:10.1017/9781009325844.*

IRENA (2020) Renewable Power Generation Costs in 2019, International Renewable Energy Agency, Abu Dhabi

Kaijser, A., & Kronsell, A. (2014). Climate change through the lens of intersectionality. *Environmental Politics*, *23*(3), 417–433. https://doi.org/10.1080/09644016.2013.835203

Keeley, B. (2015) "Why is income inequality rising?", in Income Inequality: The Gap between Rich and Poor, OECD Publishing, Paris

Labandeira, X., Labeaga, J. M., & López-Otero, X. (2017). A meta-analysis on the price elasticity of energy demand. *Energy Policy*, *102*, 549–568. https://doi.org/10.1016/j.enpol.2017.01.002

Markkanen, S., & Anger-Kraavi, A. (2019). Social impacts of climate change mitigation policies and their implications for inequality. *Climate Policy*, *19*(7), 827–844. https://doi.org/10.1080/14693062.2019.1596873

Funded by
the European Union

Moore, R. (2012) Definitions of fuel poverty: Implications for policy. Energy policy, 49, 19-26.

National Energy and Climate Plan of 2019, Decision 4/23.12.2019, FEK 4893/B/31-12-2019, https://ypen.gov.gr/wp-content/uploads/2020/11/%CE%A6%CE%95%CE%9A-%CE%92-4893.2019.pdf

National Energy Poverty Alleviation Plan of 2021, Decision PEN /GDE/ 89335/5599/2021 FEK 4447/B/28-9-2021, https://bit.ly/3J7cTU6

Nikas, A., Gkonis, N., Forouli, A., Siskos, E., Arsenopoulos, A., Papapostolou, A., Kanellou, E., Karakosta, C., & Doukas, H. (2019) Greece: From near-term actions to long-term pathways–risks and uncertainties associated with the national energy efficiency framework. In Narratives of Low-Carbon Transitions (pp. 180-198). Routledge.

Ntaintasis, E., Mirasgedis, S., & Tourkolias, C. (2019) Comparing different methodological approaches for measuring energy poverty: Evidence from a survey in the region of Attika, Greece. Energy Policy, 125, 160-169.

Nussbaumer, P., Bazilian, M., & Modi, V. (2012) Measuring energy poverty: Focusing on what matters. Renewable and Sustainable Energy Reviews, 16(1), 231-243.

OECD (2006) The Distributional Effects of Environmental Policy.

OECD (2011) "Growing Income Inequality in OECD Countries: What drives it and how can Policy tackle it." (Online Available

OECD (2012) "Reducing income inequality while boosting economic growth: Can it be done?", in Economic Policy Reforms 2012: Going for Growth, (Online) OECD Publishing, Paris.

OECD (2017) Understanding the Social Divide in Europe. (online) OECD. Available at: https://www.oecd.org/els/soc/cope-divide-europe-2017-background-report.pdf.

Osorio, P., Tobarra, M. A., & Tomás, M. (2022). *Spanish household carbon footprint by gender. 9th Hispanic-American Conference on Input-Output Analysis, Aveiro, Portugal. Https://io9.shaio.es/en/*.

Piketty, T. (2014) Capital in the Twenty -First Century. Cambridge, MA: Harvard University Press

Pye, S., Dobbins, A., Baffert, C., Brajković, J., Grgurev, I., Miglio, R., & Deane, P. (2015) Energy poverty and vulnerable consumers in the energy sector across the EU: analysis of policies and measures. Published by INSIGHT_E.

Rausch, S., Metcalf, G., & Reilly, J. (2011). Distributional Impacts of Carbon Pricing: A General Equilibrium Approach with Micro-Data for Households. Energy Economics 33

Revenga A, & Dooley, M. (2019) Income inequality beyond neoliberalism: Policies for more inclusive growth. In: G. Gertz and H. Kharas, ed., Beyond Neoliberalism: Insights from emerging markets. (online) The Brookings Institution.

Rutherford, T., Shepotylo, O., & Tarr, D. (2005) The Impact on Russia of WTO Accession and The Doha Agenda: The importance of liberalization of barriers against foreign direct investment in services for growth and poverty, The World Bank.

Rutherford, T., & Tarr D. (2004) Poverty Effects of Russia's WTO Accession: modelling "real" households and endogenous productivity effects. The World Bank

Sgaravatti, G., Tagliapietra, S., & Zachmann, G. (2021) 'National policies to shield consumers from rising energy prices', Bruegel Datasets, first published 4 November 2021, available at https://www.bruegel.org/dataset/national-policies-shield-consumers-rising-energy-prices

Siksnelyte-Butkiene, I., Streimikiene, D., Lekavicius, V., & Balezentis, T. (2021) Energy poverty indicators: A systematic literature review and comprehensive analysis of integrity. Sustainable Cities and Society, 67, 102756.

Sokołowski, J., Lewandowski, P., Kiełczewska, A., & Bouzarovski, S. (2020) A multidimensional index to measure energy poverty: the Polish case. Energy Sources, Part B: Economics, Planning, and Policy, 15(2), 92-112.

Funded by
the European Union

Stiglitz, J.E., & Greenwald, B.C. (2014) Creating a learning society: A new approach to growth, development, and social progress. Columbia University Press.

Thomson, H., & Bouzarovski, S. (2018) Addressing Energy Poverty in the European Union: State of Play and Action

Thomson, H., & Snell, C. (2016) Definitions and indicators of energy poverty across the EU. In Energy poverty handbook (pp. 101-117). Publications Office of the European Union.

Tirado Herrero, S. (2017) Energy poverty indicators: A critical review of methods. Indoor and Built Environment, 26(7), 1018-1031.

Tirado Herrero, S., & Bouzarovski, S. (2014) Energy Transitions and regional inequalities in energy poverty trends: Exploring the EU energy divide. http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2537067

Tomás, M., García-Muros, X., Alonso-Epelde, E., Arto, I., Rodríguez-Zúñiga, A., Monge, C., & González-Eguino, M. (2023). Ensuring a just energy transition: A distributional analysis of diesel tax reform in Spain with stakeholder engagement. *Energy Policy*, *177*, 113558. https://doi.org/10.1016/j.enpol.2023.113558

Tomás, M., López, L. A., & Monsalve, F. (2020). Carbon footprint, municipality size and rurality in Spain: Inequality and carbon taxation. *Journal of Cleaner Production*, *266*, 121798. https://doi.org/10.1016/j.jclepro.2020.121798

UN (2015) Inequality measurement: Development issue no 2. In Development Strategy and Policy Analysis Unit, Development Policy and Analysis Division Department of Economic and Social Affairs. (Online)

van Soest, H. L., van Vuuren, D. P., Hilaire, J., Minx, J. C., Harmsen, M. J. H. M., Krey, V., Popp, A., Riahi, K., & Luderer, G. (2019). Analysing interactions among Sustainable Development Goals with Integrated Assessment Models. *Global Transitions*, *1*, 210–225. https://doi.org/10.1016/j.glt.2019.10.004

Zhang, X. (2019) Incorporating household survey data into a CGE model. https://www.pc.gov.au/research/supporting/household-data-cge-model

Annex A: Supplementary material of microsimulation for ETD analysis.

Annex A includes more detailed information on the data adjustments, preparation, and limitations for this study.

As mentioned before, the main data source used in the microsimulation is the EU-Household budget Survey (EU-HBS). Although the EU-HBS is harmonised by EUROSTAT, some adjustment has been necessary to simulate the impacts of the ETD reform. For example, there are some data gaps in the HBSs of some countries, mainly due to the lack of disaggregation of some categories of consumption (see Table A1). Several of these data gaps have been corrected but there are still some energy products for which data are not available in some countries, because they are not included in the survey; or they are aggregated in other goods; or they are not consumed in the country. Moreover, in the HBS of some countries, data anomalies have also been detected regarding socioeconomic variables: there are countries in which some of these variables are not collected and/or variables that have missing labels.

Table A1. Missing values by country in energy expenditure categories

Energy Product missing	Member State
Natural gas	Sweden
LPG	Germany; Sweden
Liquid fuels for Heating	Czechia; Hungary; Lithuania; Romania
Coal	Finland; Greece; Italy; Latvia; Netherlands; Sweden
Other solid fuels	France; Germany; Latvia; Luxembourg; Spain; Sweden
Heat district energy	Belgium; Cyprus; Ireland; Luxembourg; Netherlands; Spain; Portugal
Petrol	France; Germany; Sweden

To correct the previous data missing we have followed the next steps: I) some countries (such as Germany and Sweden) have added the entire 045 COICOP group corresponding to household energy expenditures. To correct this data gap, the consumption structure of group 045 by ventiles has been calculated in the 2010 HBS wave and applied to the 2015 survey, and therefore we disaggregate electricity and heat energy in these MSs. II) Other MSs (such as Germany, Denmark, France and Spain) have fuel expenditure added. i.e. the data collected do not differentiate between diesel and petrol. In this case there is no possible direct solution, since the 2010 surveys did not make a disaggregation between diesel and gasoline. Therefore, for Spain, the 2017 survey provided by the INE (National Institute of Statistics of Spain) has been used[29]. For the other MS that present this issue, it has not been possible to disaggregate fuel expenditure. However, this aggregation bias should not have a deep impact on results since the price shocks on gasoline and diesel are very similar in our scenarios for these countries.

Regarding the socioeconomic variables we have follow the next process. In the case of Malta, the labels of some socioeconomic variables do not coincide with those reported in the User Manual provided by EUROSTAT. These differences have been detected in the variables of age and birth country. In the case of age, the code was modified to consider elder people over 60 in Malta, while in the rest of the countries the threshold is 65 years. In birth country, Malta does not have disaggregated people born in the rest of the EU countries and the rest of the world, so a specific label is created for this category called "Non-national".

[29] The necessary adjustments have been subsequently applied to harmonize it with the data from the rest of the countries.

Funded by the European Union

Finally, two other adjustments have been made to the expenditure variables[30]. First, since the survey data dates to 2015, it has been necessary to carry out a temporary adjustment, scaling prices from 2015 to 2020 by applying the change in the Harmonised Index of Consumer Prices to each of the COICOP categories by country[31]. Then, a micro-macro adjustment is also made because, although the use of the HBS allows a very detailed analysis of the impact of the proposed scenarios on the different types of European households, the consumption data provided by the survey does not match the data provided by the National Accounts (NA). To adjust the database developed to the macro-aggregates, the consumption data by type of good from the HBS has been scaled to the consumption levels reported in the NA.

[30] The same adjustments are made in the 2010 database, when this is the main data source for some MSs.

[31] Due to the COVID crisis, 2020 could not be an ideal year for analysing some policies. However, this is not the case for energy prices, as 2020 is the last year before the energy price crisis started. Therefore, the 2020 energy prices should be more similar to those that the Member States (MS) will experience in the future. Moreover, these prices do not include the several measures that the Member States have temporarily implemented during the energy crisis, which could affect the ETD analysis.

Funded by
the European Union