Minimum energy taxes for climate and clean air in the EU: Environmental and distributional impacts

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Abstract

Real-world policy instruments are typically characterised by a myriad of out-of-scope provisions, exemptions, and rebates, which are often ignored by stylized climate policy representations in model-based research. In this paper, we take stock of these second-best features in EU energy taxes and assess the environmental and distributional impacts of the incremental changes proposed in the revision of the Energy Taxation Directive, which dictates minimum energy tax levels across EU countries. We combine an economy-wide general equilibrium model and a household-level microsimulation model to quantify the effects on emissions of greenhouse gases and air pollutants, tax revenue, poverty, and income inequality. Three scenarios consider additive reforms as they gradually stack up energy, climate, and air pollution-based components in the design of minimum energy tax rates. Our results indicate environmental co-benefits and suggest a trade-off between emissions reduction and inequality, which can be overcome through revenue recycling. The inequality-increasing price effect is partially offset by income-side impacts (before revenue recycling) but is strengthened by cross-country heterogeneity in energy use and taxation. Overall, our findings suggest that gearing the energy tax structure towards environmental sustainability can help deliver a just transition when embedded in a broader policy package.

Keywords: General equilibrium; microsimulation; fairness; energy taxation; green transition

JEL codes: C68, D62, D63, H23, Q52

1. Introduction

Energy use is an important driver of environmental externalities, such as climate change and air pollution, yet the associated societal costs are typically not or only partially reflected in the corresponding energy price signals (Parry et al., 2014). Taxation, along with other instruments (Stiglitz, 2019), can help address environmental challenges, but current fiscal regimes contain fossil fuel subsidies, either explicitly or implicitly in the form of rebates, reductions, and exemptions.

Under the banner of the Green Deal, the European Union (EU) is charting out the energy transition on the road to climate neutrality by mid-century. As an intermediate milestone, policymakers have set the target to reduce net greenhouse gas (GHG) emissions by 55% by 2030, compared to 1990 levels (EC, 2020). In order to reach this target, the European Commission proposed a comprehensive set of policy measures, the so-called ‘Fit for 55’ package. This package aims to overhaul the existing climate and energy legislation of the EU and contains several price- and non-price-based policy initiatives to further decrease GHG emissions, among which a revision of the Energy Taxation Directive.

The Energy Taxation Directive (ETD) sets minimum levels of excise taxes on energy products across EU Member States to improve the functioning of the internal market and to avoid a race-to-the-bottom in terms of energy taxation. As indicated in the legislation (Council Directive 2003/96/EC), energy products include oil for use as heating fuel or motor fuel, gas, solid fossil fuels (including lignite, coal and coke), and electricity. Minimum tax levels are expressed per volume, for instance 359 EUR per 1000 litres of unleaded petrol (Annex I of Council Directive 2003/96/EC). As such, they do not factor in the energy content (Joule per litre) or the associated environmental harm due to climate change or air pollution.

Furthermore, the current legislation is outdated and contains various loopholes in the form of rate reductions, exemptions and rebates (Parry and Vollebergh, 2016). In particular, the legislation includes out-of-scope provisions covering biomass, mineralogical and metallurgical processes, and offer Member States the opportunity to apply rate reductions or exemptions for energy used in public and commercial transport, shipping, aviation, energy-intensive sectors, and agriculture. Importantly, this Directive is not aligned with (updated) climate ambitions, such that a revision can facilitate an efficient transition to a low-carbon economy (Rochi et al., 2014) by ensuring the right price signals that guide investment choices of households and industries to carbon-neutral options (Boyd et al., 1995).

For these reasons, the European Commission proposed a revision of the ETD in July 2021, as part of the Fit-for-55 package of the EU Green Deal. More recently, the European Scientific Advisory Board on Climate Change (ESABCC, 2024) reminded of the importance of reforming the ETD for emission reductions as one of its key recommendations, and the President of the European Commission instructed the Commissioner for Climate, Net Zero and Clean Growth to “conclude negotiations on the revision of the Energy Taxation Directive” when taking office for a second term on the first of December 2024.

Several reform options were tabled in 2021, which extend the tax base by eliminating some of the exemptions, such as intra-EU aviation, intra-EU maritime and inland shipping, the use of energy products for mineralogical as well as metallurgical processes (other than dual-use), industrial and household tax reliefs, solid biomass, and the possibility of differentiation between commercial and non-commercial use of gas oil. In terms of tax rates, the reform proposals put forward increases reflecting energy content, climate change (at 45 EUR per tonne of CO_2 in 2035), and air pollution (health impacts of fine particulate matter emissions, $PM_{2.5}$). Combined, the expansion of the tax base and the increase in the rates raise effective energy taxation in the EU roughly by one quarter (25.1%), half (53.4%), and two-thirds (65.6%) in the three reform proposals that we study in this paper (*Energy*, *Climate*, and *Air* scenarios; see Section 2.4).

These reform proposals offer an interesting setting to study the role of energy taxation in achieving environmental goals[1]. Furthermore, as ETD reform will require unanimity of the Member States, acceptability is a key concern for this policy initiative (Maestre-Andrés et al., 2019). Particularly, higher energy prices can have important distributional implications (Amores et al., 2023; Cremer et al., 2003; Speck, 1999), with potential political economy implications. Yet, a comprehensive and cross-country analysis of environmental and distributional impacts of the proposed EU energy tax reform is not available in the academic literature. A recent review (Shang, 2023) furthermore identifies the role of exemptions in shaping distributional impacts as a knowledge gap. Our assessment of the distributional impacts of the proposed removal of existing exemptions in the energy tax legislation therefore represents a valuable and timely addition to the literature.

Since the 1990s there is a growing literature on the welfare effects of environmental taxation[2]. Initially, many studies focused on the so-called “double dividend” theory (Pearce, 1991), according to which environmental taxes would not

[1] Such as the EU’s net 55% climate goal for 2030 and the air pollution targets laid out in the National Emissions Ceilings Directive.
[2] Following Eurostat definition, we can interpret environmental taxes as the collection of energy, transport, and pollution & resource taxes. In economic terms, taxing energy use on the basis of the associated CO_2 emissions is equivalent to a carbon tax (on energy use).

only improve environmental conditions but also economic conditions by recycling environmental tax revenue to reduce other distortionary taxes, such as income taxes (Goulder, 1995). While the “double dividend” literature's initial focus was on economic efficiency, the role of equity was acknowledged early on (Proost and Van Regemorter, 1995). Recently, several studies have looked at the distributional impacts of environmental taxes across households using micro-simulation models, with applications ranging from transport taxes in Spain (Gago et al., 2021) to carbon pricing in low- and middle-income countries (Dorband et al., 2019).

While micro-simulation models enable a detailed assessment of household-level impacts, they typically do not capture the production side of the economy. However, earlier work (Rausch et al., 2011; Goulder et al., 2019) illustrates that income-side effects represent a potentially important channel in shaping distributional outcomes. This may be particularly relevant in the context of the Energy Taxation Directive, as this legislation applies not only directly to households, but also to productive sectors in the economy. Here, we combine microsimulation with computable general equilibrium (CGE) modelling, which enables us to assess changes in energy taxes that apply to both households and firms, and related emissions, consumption prices, and factor incomes.

We furthermore contribute to two related strands of literature. First, the academic and political debate on carbon price floors is gaining traction in particular countries as well as internationally (Böhringer and Fischer, 2023; Parry et al., 2021; Flachsland et al., 2020; Newbery et al., 2019). We contribute to this stream of literature with an assessment of distributional impacts, as the ETD reform proposal implicitly represents a price floor across countries based on energy content, carbon intensity or damages from air pollution.

Second, this paper contributes to the literature on instrument choice to tackle environmental externalities. While much work exists on energy taxes and carbon pricing, approaches to internalize damages from air pollution into prices (and associated distributional impacts) have been scarcely researched (Kiuila et al., 2019; Mardones and Mena, 2020), although there are many real-world examples of price-based policies to control air pollution. For instance, air pollution-related taxes have been introduced in France, Sweden, and Chile; Korea differentiates diesel taxation motivated by air pollution concerns; and the US has implemented cap-and-trade policies for sulphur dioxide (SO_2) and nitrogen oxide (NO_x) emissions. Here, we assess the impact of introducing an air pollution-related component in the minimum energy taxes on the emissions of air pollutants, on the co-benefits for climate change mitigation (CO_2 emissions) and on distributional outcomes. We also quantify the synergies and trade-offs of CO_2-based energy taxation with the emissions of air pollutants, contributing to the literature on co-benefits of climate action (Vandyck et al., 2018).

The results of our analysis indicate that broadening the energy tax base and increasing energy content-based rates contributes to the Green Deal objectives of climate neutrality and zero air pollution by reducing CO_2 and air pollutant ($PM_{2.5}$, SO_2, NO_x, VOC) emissions, respectively. Introducing a climate-based component in the minimum tax rates generally benefits air quality and vice versa, reflecting air pollution damages in the tax rates tends to lower greenhouse gas emissions. These results suggest overall environmental co-benefits, despite trade-offs at the more granular sector-fuel level (biomass).

The modelling simulations furthermore quantify the distributional implications of these reforms. From our micro-simulations based on household survey data, we identify an inequality-increasing effect of the expected change in consumer prices and a counter-balancing inequality-reducing effect from the expected decline in gross labour and capital income, in line with recent studies (Goulder et al., 2019; Rausch et al., 2011; Böhringer et al., 2021a; Böhringer et al., 2021b). Jointly, expenditure- and income-side effects lead to only slightly regressive effects across income groups within countries, relatively large impact heterogeneity within income groups and a slight increase in poverty rates. Once we factor in the cross-country heterogeneity, a more pronounced regressive impact pattern across EU households emerges. However, the inequality- and poverty-increasing effects of the reform are largely reversed once we account for a within-country revenue recycling through an equal-per-capita lump sum cash transfer. Hence, our results suggest that the additional tax revenues from the increase in minimum tax rates would be enough to broadly reconcile climate and fairness goals in all EU Member States.

The rest of the paper is organized as follows. In Section 2, we describe the data, models and empirical strategy behind the analysis, as well as the policy scenarios. In Section 3, we summarize the main results in terms of CO_2 and $PM_{2.5}$

emissions, energy prices, sectoral wages, tax revenue, and the impact on poverty and inequality. Finally, in Section 4 we provide concluding remarks and discuss the policy implications of our results.

2. Methodological framework

Energy taxation affects both producer and consumer sides of the economy, as energy serves as an input into production processes and is also consumed directly by households. We therefore develop a comprehensive macro-micro modelling framework to quantify the environmental and distributional impacts of the proposed ETD reform.

This framework improves and combines different models. First, we have refined the representation of excises on energy products (coal, oil, gas, biofuels, solid biomass, and electricity) in the JRC-GEM-E3 model, capturing the details of the current ETD and its implementation in the EU Member States. Furthermore, we have extended the JRC-GEM-E3 model to cover air pollutant emissions on the basis of emission coefficients per energy use from the GAINS model (Amann et al., 2011). Additionally, we use a recently developed Indirect Tax Tool extension of the EU tax-benefit micro-simulation model EUROMOD. This model works with new micro-datasets that contain information on individual and household socio-economic characteristics with incomes and expenditures, generated by a semi-parametric matching method that combines two different EU-level household surveys. Finally, we have developed a link between the JRC-GEM-E3 and EUROMOD models, which allows us to study the distributional impacts on the household level, further extending previous work (Vandyck et al., 2021). Jointly, these refinements, extensions and model connections represent an assessment framework that enables a comprehensive analysis of environmental and socio-economic impacts, tailored to the context of energy taxation in the EU.

2.1. Economy-wide modelling

At the macro level, we use a general equilibrium model to evaluate the economic and environmental impacts of the proposed ETD reform. Using a CGE model enables the assessment of both expenditure- and income-side channels of distributional impacts of policies.

In particular, we use the JRC-GEM-E3 model, a multi-sector, multi-country, energy-economy model with global coverage and EU Member State detail. With a detailed sectoral disaggregation of energy activities (from extraction to production to distribution sectors) as well as endogenous mechanisms to adjust energy use and mitigate carbon emissions, the JRC-GEM-E3 has been extensively used for the economic analysis of climate and energy policy impacts. For examples of recent climate policy applications of this model, we refer to Weitzel et al. (2019, 2022) and Tamba et al. (2022). Disaggregated into 31 sectors of activity (see Appendix A.1), firms are cost-minimizing with Constant Elasticity of Substitution production functions. Sectors are interlinked by providing goods and services as intermediate production inputs to other sectors. Households are the owner of the factors of production (labour and capital) and thereby receive income, used to maximize Stone-Geary utility through consumption. Government behaviour is considered exogenous, while bilateral trade-flows adjust to prices according to a standard Armington specification. The model is recursive-dynamic, achieving an equilibrium for goods and services markets, and for factors of production through adjustments in prices in 5-year steps. The model and its mathematical equations are documented in Capros et al. (2013), and the underlying input-output data is described in Aguiar et al. (2019). Given the relevance of aviation in the ETD reform proposal (coverage extending to intra-EU aviation, see Section 2.4), we update the elasticity of substitution (see Appendix A.1) between energy and the capital-labour bundle in this sector to values used (0.1) in similar models with a dedicated focus on air transport (Winchester et al., 2015). The model covers existing tax systems, including the EU Emission Trading System (ETS), which is represented by the carbon price signal in this paper.

For this exercise, the model has been refined in terms of the representation of current energy excises in the EU, capturing exemptions, rebates, and out-of-scope provisions (e.g., dual use, electrolytic processes). Firms consume energy products as inputs into the production function. For households, we distinguish between energy carriers for heating and appliances, and energy use for private transportation. To improve the representation of energy excises, we introduce new model parameters for firms and households that represent a unit excise tax per volume of energy consumption (ton of oil equivalent in the model). These new model parameters enable the implementation of the current-policy baseline and the reform scenarios described below, and are characterised by four dimensions: per country, per year, per sector (also distinguishing between heating and motor fuels for households) and per energy product.

To study the impact of the various proposal on air pollutant emissions, the JRC-GEM-E3 model was further developed to cover emissions of NO_x, $PM_{2.5}$ and SO_2 for all sectors, energy carriers and countries in the EU. Air pollutant emissions were provided by the GAINS model[3] (IIASA), and corresponding emission control policies are in line with the baseline of the Second Clean Air Outlook (EC, 2021b) for the year 2030. After mapping the sectors of both models, these emissions were converted into emission factors by dividing with the corresponding drivers: energy use or economic activity. Emissions that could not be clearly linked to either energy use or sectoral activity were kept fixed across scenarios. Emission factors for 2030 were then applied to the year 2035, which could lead to slight overestimation of emission reductions in 2035 if emission factors are decreasing faster in regions were the ETD scenarios are particularly impactful. While the JRC-GEM-E3 model combines economy-wide coverage with sector- and fuel-specific detail, a few caveats should be considered when interpreting the results on air pollutant emissions. First, emissions related to the use of solid biomass for energy in industry are not accounted for. Second, the model does not capture the split between diesel and petrol, hence may underestimate the benefits of the air pollution component in the minimum rates in terms NO_x emission reductions.

2.2. Household-level microsimulation

To assess the distributional consequences of the expected changes in consumer prices, sector-specific wages and capital income, we use EUROMOD, the EU-wide tax-benefit micro-simulation model (see Sutherland and Figari, 2013 and Maier et al., 2022, for more information). EUROMOD combines country-specific coded policy rules with representative household microdata based on the European Union Statistics on Income and Living Conditions database (EU-SILC) to simulate tax liabilities and cash benefit entitlements. Therefore, EUROMOD simulations take into account (interactions between) tax-benefit instruments to generate the disposable household income after direct taxes and cash benefits. Differently from models based on other micro-datasets, by working with disposable income based on EU-SILC, our results are directly comparable with the official statistics on poverty and inequality published by Eurostat.

EUROMOD Indirect Tax Tool (ITT) extends the scope of the EUROMOD core simulations, allowing for the joint analysis of direct and indirect taxation. To simulate indirect tax liabilities from household consumption, EUROMOD-ITT combines the underlying EU-SILC data with household expenditure information for more than 200 commodity categories from the 2010 harmonised Eurostat Household Budget Surveys (EU-HBS), the latest available release at the time this model was developed.[4] To combine expenditure and income microdata, a semi-parametric matching procedure developed by Akoğuz et al. (2020) is used with HBS and EU-SILC as source and recipient datasets, respectively. This consists of three main steps. Firstly, a common set of relevant covariates is identified in the source and in the recipient dataset, including socio-economic characteristics of the household (head). Secondly, in the source dataset, consumption goods are aggregated into 20 macro-category and expressed in terms of consumption shares of income. These aggregated consumption shares are then regressed against the set of covariates identified in the first step. Thirdly, the estimated coefficients are then used to construct fitted shares of consumption in both the source and in the recipient dataset (i.e in each of these dataset, 20 fitted consumption shares will be calculated for any household based on their covariate). A Mahalanobis distance metric is then used to find the closest match between any record in the source and in the recipient dataset.[5] When running the analysis for policy years which are successive to the year the underlying dataset refers to, appropriate uprating factors are used to update consumption and incomes

[3] https://iiasa.ac.at/web/home/research/researchPrograms/air/GAINS.html

[4] EUROSTAT harmonized 2010 HBS datasets for Austria and the Netherlands were not available and the data of Luxembourg did not contain information on income. For Austria and Luxembourg, the ITT uses national HBS data. In particular, for Luxembourg the 2013 national HBS was used as this was the first year where the income information was adequate for the imputation method. For the Netherlands, EUROSTAT 2015 HBS dataset was employed instead.

[5] For a comprehensive description of the Indirect Tax Tool, including the construction of the underlying micro dataset, the simulation of consumption taxes as well as the validation of the model, we refer to Akoğuz et al. (2020) and Decoster et al. (2010). EUROMOD is an open source publicly accessible model. For more information see: https://euromod-web.jrc.ec.europa.eu/overview/extended-functionalities

in nominal terms. Starting from the household disposable income simulated by EUROMOD, the ITT applies the indirect taxation rules in place in each country to simulate households' adjusted disposable income after direct taxes, cash benefits and indirect taxation. For recent applications of this model, see Amores et al (2023).

2.3. Top-down macro-micro link

Following the general approach of Vandyck and Van Regemorter (2014) and Vandyck et al. (2021), we link the general equilibrium and micro-simulation models in a "top-down" fashion, feeding the outcomes of the CGE model into the micro-simulation analysis. The link is unidirectional, as no information is passed on from the micro to the macro level. The macro outcomes that are fed into the micro model for each of the 27 EU countries are: i) consumer price changes for 14 aggregate product categories, ii) gross wages changes for 6 sectors, iii) gross capital income changes, and iv) government revenues (which are used to design compensatory measures). Jointly, this set of information that links both models comprises approximately 600 variables.

Consumption categories from input-output data and EUROMOD-ITT use different classifications (GTAP versus COICOP). To map them, we use the matrices developed by Cai and Vandyck (2020). Moreover, baseline scenarios of the two models are aligned. To this end, the consumption of each household in the EUROMOD-ITT is adjusted proportionally in order to ensure that the aggregate shares of consumption expenditure by group of goods and services (e.g. "Education" or "Food") match those of the JRC-GEM-E3 model.

To account for the welfare impact of *consumer price changes*, consumption expenditures of each household are adjusted to account for the changes in prices of goods and services, while keeping constant the quantities consumed in each category. This effect can be interpreted as the additional income that a household would need in order to keep its consumption basket unchanged under the new prices.[6] This welfare effect driven by consumer prices is what we call the "price effect" in the remainder of the paper.

To account for the welfare impact of *factor price changes* (i.e. gross labour and capital income), we use the uprating factors and the tax-benefit rules coded in EUROMOD-ITT. This allows us to explicitly consider the inter-play of taxes and benefits, i.e. to simulate the change in household disposable income given the expected changes in gross labour and capital income, accounting for the interaction of direct taxes (e.g. personal income tax) and cash benefits (e.g. child benefits, social assistance, etc.). This additional welfare effect through changes in household disposable income can be interpreted as the additional monetary resources a household would need to keep its savings (or debt) constant, or unchanged with respect to the baseline. This welfare effect driven by income changes is labelled as the "income effect" in the results section.

Our modelling extends previous methodological approaches (Vandyck et al., 2021) along several lines, beyond the expansion of the country coverage. First, we extend the income channel by considering heterogeneous impacts across sectors. In particular, while Vandyck et al. (2021) consider only one wage change rate for all workers, in this study the macro model estimates the expected change in gross wages across broad sectors of activity, and we translate these changes into the micro model. Considering this additional dimension is a relevant extension in the context of this paper, as the impacts of energy tax reforms are heterogeneous across (workers in different) sectors and these workers are located at different points of the income distribution between and within countries. After mapping the different sector classifications used by the two models, we end-up with six sectors (see Appendix A): i) Agriculture, including agricultural and fishing activities; ii) Industry, including mining, manufacturing, and utilities; iii) Construction; iv) Transport; v) Other services, including wholesale and retail, communication, financial services, banking; and vi) Public services, including public administration, health and education.[7] Second, we decompose the distributional effects distinguishing the roles of price and income effects, as their expected effects can be, a priori, very different. Third, we present synthetic indicators to measure income inequality (Gini coefficient) and impacts on the bottom-part of the

[6] As discussed by Vandyck et al. (2021), this could be interpreted as derived from Leontief preferences. This concept matches the definition of Compensating Variation as a money metric of the welfare change exerted by changes in consumer prices (King, 1983).
[7] Within sectors, we employ a uniform change rate, as the macro model does not have further information (e.g. skills nor occupation) to consider more disaggregated effects and identify more precisely who would experience the strongest/weakest wage changes.

distribution (at-risk-of-poverty rates, AROP). These synthetic figures provide a more comprehensive view and facilitate broader comparison of the magnitude of these effects in the multi-country, multi-scenario setting of the paper.

The final mechanism concerns the recycling of the simulated government revenues to compensate households. We simulate a uniform lump-sum transfer per individual, which recycles all the extra revenues raised through increased taxation from the household sector through equal-amount cash transfer to all individuals of the population within the same country, including children and adults out of the labour force. For the distributional analysis, we do not redistribute the additional revenues obtained from firms to households. This is a conservative assumption that reflects real-world situations where government budgets are constrained and need to satisfy other demands, e.g. to support other areas of the transition such as financing investment in low-carbon technologies to enable industrial decarbonisation.

2.4. Scenarios

The aim of the analysis is to compare the impacts of the proposed reform options of the EU Energy Taxation Directive against the backdrop of current energy taxation in the EU. Therefore, one crucial element of the analysis is to capture accurately the details of existing energy and proposed excises across EU countries, sectors, and energy carriers. We assess three scenarios that differ in terms of the tax base and rates by comparing them to the current-policy Reference (or baseline). The following subsections describe in detail the estimation of effective tax rates in the Reference and the policy scenarios. Tabel 1 lists the EU-wide minimum tax rates across energy products and scenarios.

2.4.1. Reference: Current ETD legislation

The ETD defines the scope of energy taxation, the conditions for exemptions and reductions, and sets minimum levels of taxation. Member States retain competence to implement rates above these minimum levels or apply optional exemptions and reductions according to their own national needs within the provisions set out in the ETD. These harmonized rules result in significant heterogeneity in both nominal and effective energy tax rates across uses and countries (OECD, 2022). The same nominal rates can imply different effective rates through the existence of exemptions, reductions, and rebates.

Tabel 1. Tax rates across energy products in the Reference and reform scenarios

EUR / GJ, 2035, non-indexed	**Reference**	**Energy**	**Climate** *Increment*	**Climate** *Total*	**Air** *Increment*	**Air** *Total*
Motor fuels						
Petrol	10.74	10.75	3.15	13.90	0.23	14.13
Gasoil	9.08	10.75	3.15	13.90	0.55	14.45
Kerosene (aviation)	0.00	10.75	3.15	13.90	0.05	13.95
LPG	2.66	10.75	2.70	13.45	0.19	13.64
Bioethanol E100	0.00	5.38	0.00	5.38	0.35	5.73
Biodiesel B100	0.00	5.38	0.00	5.38	0.83	6.21
Heating fuels and fuels for agriculture, stationary motors, maritime and inland shipping (including fishery)						
Gas oil	0.58	0.9	3.15	4.05	0.37	4.42
Heavy fuel oil	0.37	0.9	3.60	4.50	0.37	4.87
Coal and coke, business	0.15	0.9	4.05	4.95	7.41	12.36
Coal and coke, non-business	0.30	0.9	4.05	4.95	7.41	12.36
Kerosene business and non-business	0.00	0.9	3.15	4.05	0.37	4.42
LPG business and non-business	0.00	0.9	3.15	4.05	0.37	4.42
LPG (other)*	0.87	0.9	3.15	4.05	0.37	4.42
Natural gas business	0.15	0.9	2.70	3.60	0.32	3.92
Natural gas non business and other*	0.30	0.9	2.70	3.60	0.32	3.92
Biomass (wood and pellets)	0.00	0.45	0.00	0.45	7.40	7.85
Other						
Electricity	0.00	0.15	0.00	0.15	0.00	0.15

*other: agriculture and stationary motors

In order to reflect this heterogeneity in the current-policy baseline, our analysis is based on a comprehensive data collection exercise, gathering inputs directly from Member States on rates, reductions, exemptions and rebates. In addition, the exercise required detailed calculations on the share of industrial energy use falling out of scope of the ETD according to Article 2, using energy balances published by Eurostat and the JRC-IDEES database.[8] For instance, out-of-scope provisions apply to dual use and electrolytic and mineralogical processes. Capturing correctly the tax base required four steps. First, we adjust for the auto-production of electricity and heat by disaggregating EUROSTAT energy balances by industry according to the installed capacities reported by S&P Global Platts "World Electric Power Plant Database" (S&P Global Platts, 2019). Second, we account for the consumption of energy for non-energy uses (e.g. feedstocks) by disaggregating EUROSTAT energy balances on the basis of the "memo items" available from the IEA's Extended World Energy Balances (International Energy Agency, 2020). Third, we calculate the total amount of energy used by each industrial sector by subtracting the feedbacks from coke ovens, blast furnaces, and power plants from the total amount of energy inputs, as only the inputs from external sources are considered to be taxable and the feedbacks of energy carriers that are produced internally are considered exempt from additional taxation. Fourth, we classify total energy use by industry into in/out-of-scope categories according to the shares resulting from assigning the processes included in the detailed energy balances of the JRC-IDEES database (Mantzos et al., 2017) for the year 2015 to the categories considered in the ETD (and assume they remain constant over 2015-2018). Out-of-scope categories include chemical reduction, electrolysis, metallurgical processes, mineralogical processes, other dual uses, wood and wood products, peat, electricity, and uses other than motor or heating fuels. We also account for specific rates on heat generation in combined heat and power (CHP) generation.

We implement the resulting effective tax rates in the JRC-GEM-E3 baseline using a detailed mapping of ETD energy carriers and uses to energy suppliers and consumers in the CGE model, building on abovementioned calculations and detailed energy balances. One caveat of the modelling framework in this analysis is that diesel and petrol are not represented separately in the JRC-GEM-E3 model, so effective tax rates on oil products are modelled in an aggregated way. Effective energy tax rates and other implemented climate policies feed into an input-output balancing procedure (Wojtowicz et al., 2019), which allows demographic and economic assumptions to be combined with exogenous projections of energy use and greenhouse gas emissions in a consistent multi-regional input-output format, compatible with the GTAP database underpinning the JRC-GEM-E3 model. The projections are aligned to the PRIMES model Reference, including policies before implementation of newly proposed measures in the Fit-for-55 package. Real effective energy excises decline over time with inflation as minimum tax levels are not indexed to inflation in the current legislation.

2.4.2. Reform scenarios: Energy, Climate, Air

The first scenario studies the impact of a broadening of the scope while reforming the tax rate to reflect the energy content of different energy carriers[9]. The second and third scenarios incrementally add a CO_2-based and an air pollution-based component to the tax rates, aiming to contribute to the Green Deal objectives of climate neutrality and zero air pollution. We label these scenarios *Energy*, *Climate*, and *Air*, respectively, which match scenarios 2a, 3a and 3c in the European Commission's proposal (EC, 2021a).

The policy scenarios are additive as the rates are based on energy-content, energy- *plus* carbon-content, or energy- *plus* carbon-content *plus* a component related to damages from air pollution. All three scenarios involve a 10-year transition period starting in 2023 for selected products and sectors (in particular gas and aviation). The ETD targets end use of energy, such that e.g. the electricity generation sector is out-of-scope.

In the first scenario, *Energy*, the ETD minimum rates are revised to be based on energy content (e.g. expressed in Joule), rather than energy volumes consumed (in litres of kilogrammes). This eliminates the disadvantage implicit in volume-based taxes for fuels with comparably lower energy content, such as biofuels. The European Commission proposed a set of new minimum rates in EUR per Gigajoule, harmonized across fuels used for a same use (heating or motor). In this scenario, the tax base is also expanded to remove exemptions: a number of out-of-scope industrial

[8] See Annex 10: Quantification of the industrial energy consumption within the scope of Article 2 of the Energy Taxation Directive, SWD 641 final.

[9] For the same volume (litre) or mass (kg), energy products have varying energy content (e.g. Joule per litre) and greenhouse gas and air pollutant emissions. For instance, a uniform tax *per litre* of petrol and gasoil would imply unequal taxation between petrol and gasoil on an energy content or emissions basis.

processes are brought back into scope, namely: (i) products used for metallurgical processes in the iron and steel and the non-ferrous metal industries, (ii) those used for mineralogical processes and (iii) the share of energy input to produce heat in combined heat and power generation. For all land transport, the minimum rates apply. Furthermore, the tax base is extended to cover biofuels and intra-EU aviation and navigation. While traditionally energy taxes have served a revenue-raising purpose, the energy content-based taxation can be motivated also in the context of the EU targets on energy efficiency, and to some extent can be justified by the literature on internalities (Allcott et al., 2014).

The *Energy* scenario we implement here does not include the "ranking obligation" that was mentioned in the policy proposal: "Member States must ensure that the environmental performance and use of each product is reflected in their national tax rate by respecting the ranking between the different rates." For some countries, this rule would imply necessary changes in the tax rates. However, it is a priori unclear how countries would implement such ranking, as it could be achieved by either raising or lowering existing tax rates.

In the second scenario *Climate*, the same elements of the *Energy* scenario are included, and in addition, the minimum tax rates are increased to include a component reflecting the carbon content of the fuel. In this scenario, fuels with a higher carbon content[10] are taxed at higher rate for the same amount of energy use in GJ, representing the corresponding contribution to global warming (CO_2 only). This 'climate component' in the energy tax rates is thus equivalent to a carbon tax on energy use. Implicitly, this proposal thus introduces a carbon price floor of 45€/tCO_2 in 2035 across the EU for the sectors covered, with the goal of aligning energy taxation with climate change mitigation targets. Intra-EU aviation is excluded as it is covered by the EU ETS system, while maritime transport is included since it was not covered by the EU ETS at the time of the proposal.

Finally, in a third scenario *Air*, an air pollution component is added to the rates of the *Climate* scenario in order to reflect the associated damages from air pollution. This component is based on an EU-wide valuation of mortality associated to air pollution from fine particulate matter ($PM_{2.5}$) and NO_x emissions. The calculation, described in detail by the European Commission (2021), takes a conservative approach and disregards technology characteristics (e.g. end-of-pipe abatement), impact heterogeneity across space, and damages from air pollution from other channels (morbidity, crop yields, eutrophication, etc.) and pollutants (SO_2, ground-level ozone). The valuation of mortality is based on years of life lost, with an assumed EU-wide valuation of 79'500 EUR_{2005} per life year lost. Combining this estimate with emission coefficients from the EMEP/EEA guidebook[11] gives the resulting tax rates per energy use as shown in Tabel 1 (see Annex A.4 for further details). While literature acknowledges that a pure Pigouvian tax on air pollution is technologically infeasible (Jacobsen et al., 2022), the proposed air pollution component can complement other forms of regulation to mitigate air pollution.

2.4.3. Resulting tax rates

Figure 1 presents an overview of the scenarios across EU energy use. The figure illustrates effective energy tax rates – accounting for exemptions, rebates, and out-of-scope provisions – across the projected baseline tax base (in 2035) disaggregated by energy product (panel a), country (panel b), and sector (panel c).

Panel a of the figure illustrates the heterogeneity across fuels, sectors and countries in energy excises that are currently applied. Note that the figure only shows energy excise taxes and does not include other levies such as carbon taxes and various charges that may apply on electricity. Overall, the figure shows that particularly the *Energy* and *Climate* scenarios raise tax rates for a substantial amount of energy use, while the *Air* scenario has a more limited, yet concentrated impact on tax rates.

Cutting across the fuel dimension, panel b of the figure illustrates that the proposed reform options have little or no impact on excises on electricity. Intentionally, excises on electricity are not raised to enable an electrification of end-use while the Emission Trading System decarbonizes electricity generation. Tax rate increases for gas, coal, and oil aim

[10] The emission factors used for the conversion for motor fuels are 0.07 tCO_2/GJ for petrol, gasoil, and kerosene, and 0.06 tCO_2/GJ for LPG and natural gas. For heating fuels (plus fuels for agriculture, stationary motors, maritime and inland shipping, including fishery), fuel emission factors are 0.09 tCO_2/GJ for coal and cokes, 0.08 tCO_2/GJ for heavy fuel oil, 0.07 tCO_2/GJ for gasoil, kerosene, and LPG, 0.06 tCO_2/GJ for natural gas, and zero for bio-energy and electricity.
[11] https://www.eea.europa.eu/publications/emep-eea-guidebook-2019

to level the playing field and shift final energy use towards electricity. Final energy use of coal is relatively limited in magnitude, but corresponding rate increases are large, particularly in the *Climate* and *Air* scenario.

A comparison across countries (panel c) confirms the difference in starting points, with e.g. lower excises and larger changes in the scenarios for Poland compared to France. This heterogeneity will drive part of the distributional impacts that we assess later in the paper.

While the analysis accounts for tax rate changes on both the household and firm side, it is worthwhile to pay particular attention to the rate changes that apply to household energy use, as these will have a direct impact on socio-economic outcomes. In terms of household heating, rates are generally low (compared to transport), as many Member States make use of exemptions present in the current ETD. The *Energy* scenario leads to a general harmonization of minimum rates across fuels and Member States. The majority of countries is currently taxing energy for household heating less than the proposed new minima based on energy content. The inclusion of carbon content penalises the most carbon intensive fuels, with oil heating and heating from solids experiencing a larger increase in minimum rates than natural gas. Countries where households heavily rely on solid fuels for space heating (e.g. Poland, Czech Republic, Bulgaria), or on fuel oil (e.g. Belgium, Cyprus, Greece), or both (Ireland) will be more strongly affected by the ETD reform. Similarly, the inclusion of the air pollution component leads to more than a doubling of minimum rates for solids used for household heating, affecting households in countries most reliant on such fuels. In general, the pattern of tax rates (changes) in the services sector is similar to the one for residential energy use of households.

For household motor fuels, the rates are significantly higher than for heating in the baseline, as no exemptions are possible. The rates for gasoline (petrol) are higher than for gasoil in all Member States. Only 4 countries are significantly affected by new minimum rates on petrol for household use in the *Energy* scenario (Bulgaria, Cyprus, Hungary, and Poland). Accounting for energy, carbon, and air pollution content (*Air* scenario), baseline rates remain higher than new minima in 9 Member States. In contrast, for diesel (gasoil) where rates are lower in the baseline, the new minimum rates impact 21 of 27 Member States in the *Energy* scenario alone (particularly Bulgaria, Hungary, Poland, Luxembourg, and Romania), thereby removing the existing favouring of diesel over petrol in excise taxes. Accounting for carbon and air pollution content increases minimum rates compared to the baseline in all Member States. For those countries with very high shares of diesel in the motor fuel mix (more than 60 per cent for Spain, Portugal, Latvia, Lithuania, and Slovenia), the increase in minimum rates for gasoil will result in higher motor fuel cost. The changes in rates for commercial transport across baseline and scenarios are similar as those of motor fuels for households. However, the fuel mix in commercial transport is more homogeneous in the EU, with over 90 per cent of diesel (gasoil) in fuel for trucks and light-duty vehicles in most Member States, resulting in increases in transport services costs across the economy.

Other sectors of the economy where the ETD reform proposals introduce notable changes are industry and air transport (kerosene), where the proposed legislation closes various loopholes that characterise the current ETD legislation (panel d).

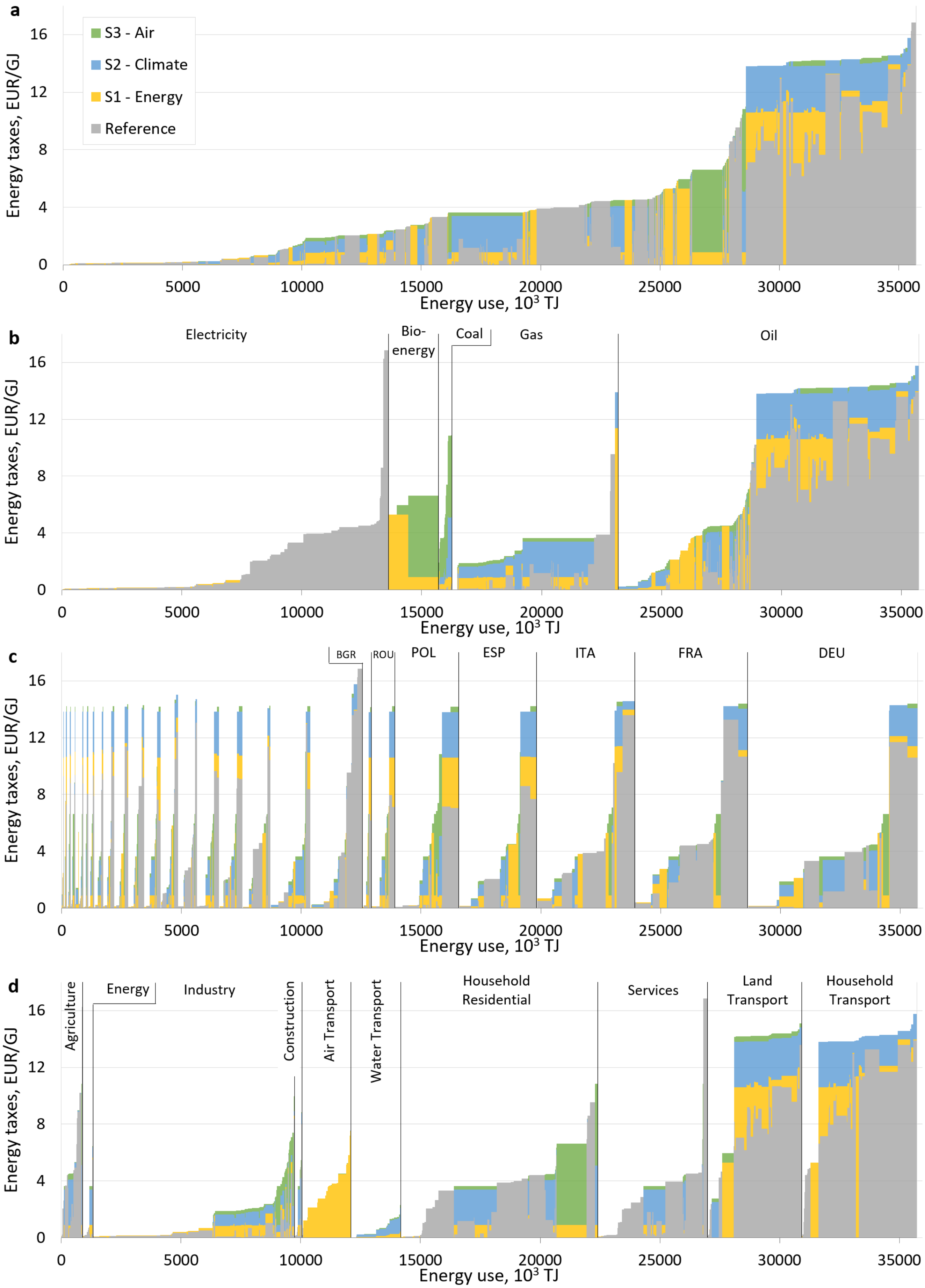

Figure 1. Effective energy tax rates across scenarios. a) Total, b) by energy product, c) by country, d) by sector. For sector mapping, see Appendix A.

3. Results

The result section starts with a presentation of the key outcomes at the country level: changes in emissions, wages, household energy prices, tax revenue and welfare across the 3 scenarios and 27 Member States. These results form the basis for the distributional analysis that follows. We assess within-country impact heterogeneity in Sections 3.2 and 3.3, presenting the impacts on poverty and inequality within countries in Section 3.2, and a deeper dive into vertical (across income groups) and horizontal (within income groups) equity in Section 3.3. Next, we add cross-country heterogeneity as a channel of distributional impacts in Section 3.4. Finally, we combine environmental and distributional outcomes to discuss the results in light of the fairness and public support challenges faced by the just transition (Section 3.5).

Throughout the section, results are presented as changes from the current-policy baseline in 2035, as the proposed phase-in of the new rates will have been completed by that year. Overall, the approach is to focus the narrative on consistent findings across scenario-country-fuel-sector combinations while leveraging the depth of the assessment to explain results and to highlight particular cases as examples.

3.1. Environmental, economic, fiscal and welfare impact at country level

An overview of the main country-level effects on emissions, wages, energy prices, and tax revenues is shown in Figure 2 (panels a, b, c and d, respectively). Figures SI-1 to SI-5 and Table SI-1 in Appendix B provide additional results.

Higher energy taxes leading to an increase in prices induce a fuel shift (Labandeira et al., 2017) and investments in energy efficiency (Antonietti and Fontini, 2019). As a consequence, the proposed ETD reform will reduce emissions associated with the use of energy, fossil fuels in particular. We quantify these emission reductions, as illustrated in panel a of Figure 2. The figure shows two key environmental indicators: emissions of CO_2 from energy use (climate change) and of fine particulate matter ($PM_{2.5}$, air pollution). Overall, the results indicate that broadening the tax base and raising the rates would contribute to the objectives of the Green Deal by reducing CO_2 emissions generally between 0 and 5% in the *Energy* scenario, compared to the reference in the year 2035 (when the transition has ended). This magnitude suggests that additional measures of the Fit-for-55 package are needed to deliver on the ambition for climate mitigation. CO2 emission reductions in Luxembourg reach 8.7% due to taxation on oil use in transport, with about half the emission reduction coming from air transport, and the other half from land transport (including household private transport). For Central Eastern European countries such as Poland, Bulgaria (transport) and Romania (transport; gas in residential energy) the CO_2 emission reductions from household energy are more pronounced than overall EU averages, exceeding 7% in 2035 compared to the baseline. For some countries, like France and Ireland, percentage CO_2 reductions are stronger for firms than for households, because the latter already face relatively high excises on fossil fuels for heating and transport under the current taxation systems represented in the baseline. These countries do see small reductions in fine particulate matter emissions due to the taxes introduced on biomass for residential heating and biofuels in transport. Overall, emission reductions for fine particulate matter range in the same 0-5% ballpark, with slightly more pronounced reductions for households in cases with substantial use of biomass (Bulgaria) and coal (Poland).

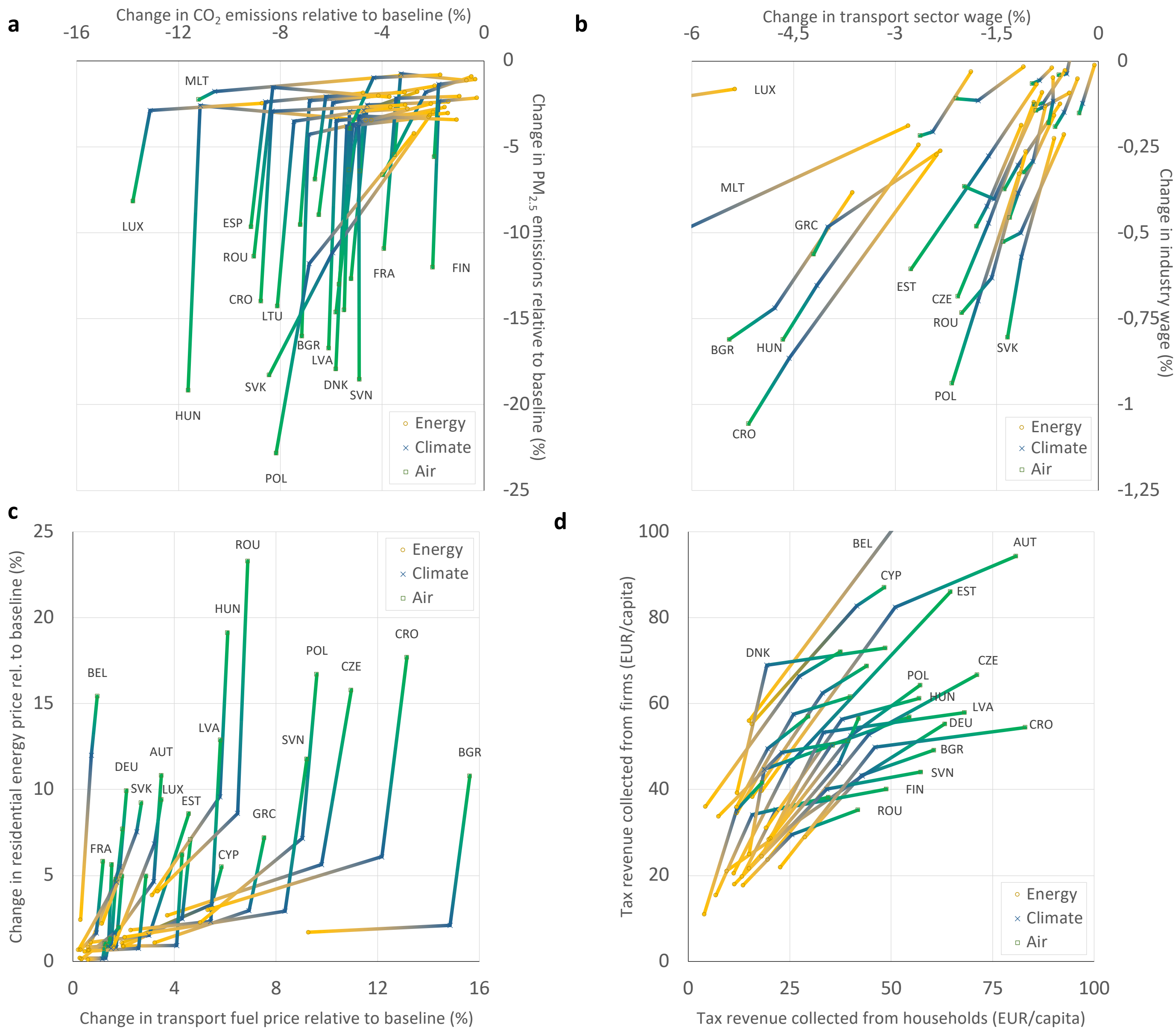

Figure 2. Impact on emissions, prices and tax revenue compared to the baseline in 2035

The *Climate* scenario further raises EU-wide CO_2 emission reduction from about 2% in the *Energy* scenario to 5%, with stronger relative reduction from households (more than 8% reduction compared to baseline) than from firms (-4% vs. baseline). These reductions mostly stem from reduced oil and gas use, as final use of coal is limited in volume. The higher magnitudes come with larger heterogeneity across countries, driven by differences in existing rate structure, fuel use and sector composition of the economy. For instance, the land transport sector is an important factor in the Hungarian economy and in the emission reductions, while the water transport sector plays a large role in Malta. Results indicate a CO_2 emission reduction of around 20% for households in Bulgaria (transport), Hungary, Romania (transport and gas in residential energy) and Poland. In the latter, increased taxation on coal use for residential heating and in industry leads to relatively strong co-benefits for air quality, with a 12% reduction of $PM_{2.5}$ emissions in the *Climate* scenario. In general, results illustrate air quality co-benefits of climate-based taxation, with reductions of $PM_{2.5}$ emissions increasing from 2.5% (*Energy*) to 3.7% (*Climate*) relative to the baseline. However, a deeper dive also illustrates trade-offs. Although the effect is limited in size, the addition of a CO2-based component in the energy taxation raises $PM_{2.5}$ emissions from residential energy use in some countries (Romania, Germany, Hungary) by inducing a shift from gas- to biomass-based heating. Results indicate stronger co-benefits for other air pollutants, such as SO_2 and VOC, and particularly for NO_x given the increase in excises on oil in transport (Figure SI-2 in Appendix B).

The *Air* scenario leads to substantial reductions in $PM_{2.5}$ emissions (-13%), exceeding a reduction of 5% in most countries, reaching approximately 20% in several countries (Hungary, Poland, Slovakia, Slovenia) and exceeding 20%

for households on the EU average. These results illustrate that accounting for air pollution externalities in energy prices can bring significant benefits by limiting the use of fossil fuels and biomass. The numerical results furthermore point to climate co-benefits of air pollution-based taxes, raising CO_2 emission reductions from 5.2% in the *Climate* scenario to 5.7% in the *Air* scenario. These co-benefits are relatively strong for Poland and Slovakia due to coal use by households and industry, respectively, but are generally more modest than in global studies that include large coal-based electricity generation sectors (Parry et al., 2015). Note that the additive scenario design may affect the magnitude of our estimates, as energy efficiency enhancements already occur in the *Energy* and *Climate* scenarios, and since investments in energy efficiency are characterized by increasing marginal costs. As in the *Climate* scenario, we find minor trade-offs clean air and climate change in a few countries. With biomass taxation, the effect on climate change mitigation could go either way, in principle. In most instances, energy efficiency and electrification prevail such that overall effect on CO_2 mitigation is positive for all countries. Trade-offs arise for CO_2 emissions of households in a handful of countries due to a biomass-to-gas shift in the residential energy mix, but the magnitude is limited (e.g. household CO_2 reduction falls from 17.9% in the *Climate* scenario to 17.6% in the *Air* scenario for Romania).

The combination of current tax base and rates, fuel mix and sector composition in the economy further determines the economic implications of the proposed energy tax reforms. Factor prices changes are generally limited, but most pronounced in the transport sector (panel b), where fuel inputs represent an important component in overall production costs. In line with above-mentioned results, impacts on wages are relatively strong in the transport sectors in Central and Eastern European countries, Luxembourg (land and air transport), Malta (water transport), and Greece (air and water transport). Industry wage reductions are more modest and generally do not exceed 1% compared to the baseline level.

Energy prices for residential and private household transport (panel c) stay within a +5% range for most countries under *Energy* scenario. The *Climate* scenario shifts this range to the order of +10%, generally affecting more the transport fuel prices as carbon intensity of energy mix for residential heating (electricity, gas, biomass) is typically lower than oil in transport.

Results indicate the strongest price increases in countries with currently relatively low energy taxes for households (including Romania, Hungary, and Croatia). For countries with a significant share of bioenergy in projected residential energy mix, such as Bulgaria, the price changes in panel c of Figure 2 move along the horizontal axis (transport fuel price) from the *Energy* to the *Climate* scenario, as the *Climate* scenario does not raise the tax rates for bioenergy. From the *Climate* to the *Air* scenario, prices then move along the vertical axis as the *Air* scenario increases minimum tax rates for bioenergy. Other countries follow a different pattern. Belgium, for instance, moves mainly along the vertical axis, as current excises are high for household transport and low for residential energy use, and since residential heating relies on oil more than in most other EU countries.

These observations also apply to commercial buildings, explaining the relatively large tax revenue collected from firms in Belgium (panel d of Figure 2), where the service sector represents a significant share of the economy. Another example with relatively high additional tax revenue from the firm side is Denmark, where household residential energy consumption is largely electricity-based and gas and oil face high excise taxes under current regulation. Tax revenue from the firm side in Denmark largely comes from the transport (air and land transport in *Energy* scenario; also water transport in the *Climate* scenario), industry and agriculture (*Climate* scenario) sectors. Considering all EU countries, additional tax revenue from households/firms tends to be below 25/40 EUR per capita in the year 2035 for the *Energy* scenario, shifting upwards towards 50/80 EUR per capita in the *Climate* scenario and asymmetrically increasing to 80/90 EUR per capita in the *Air* scenario. Compared to the changes in emissions, the tax revenue results indicate larger contributions to the aggregate outcome from the firm side, which has a relatively large tax base (energy use) but generally smaller rate increases (e.g. gas use in industry).

The factor and consumption price changes illustrated in panels b and c of Figure 2 imply negative welfare effects that are moderate in magnitude and heterogeneous across countries. Without accounting for the potential use of additional tax revenues and for the environmental benefits, results indicate average EU27 welfare losses of 0.35%, 0.75% and 1.1% of baseline household disposable income in the *Energy*, *Climate* and *Air* scenarios.

In the *Energy* scenario, the negative welfare impact ranges from 0.04% in the Netherlands to 1.25% in Bulgaria (Figure SI-6). This min-max range, led by the same two countries at opposite ends, shifts to 0.16%-2% and 0.2%-2.7% in the *Climate* and *Air* scenarios, respectively. Although there is some country re-ranking across scenarios, in general, we observe that the strongest effects take place in Central Eastern European countries, while the mildest is observed in Western and Northern European countries. Southern European countries tend to be somewhere in between these two groups. This is generally consistent with the expected heterogeneous effects on factor and consumption prices discussed above across EU regions.

On average, the price effect (via increased consumption and energy prices) tends to dominate over the income effect (via factor price changes), although its relative weight in the total welfare impact largely differs across countries. In some countries (e.g. Finland, Croatia and Cyprus) the price effect explains 2/3 or more of the total welfare effect in the *Energy* scenario, whereas the opposite holds true in Portugal, Germany, Denmark and Luxembourg, where about 2/3 or more of the welfare effect is driven by the reduction in incomes relative to baseline levels (see additional results in Figures SI-6 to SI-8 and Table SI-2 in Appendix B). Although price and income effects largely vary across countries, both tend to be larger in lower and middle-income EU countries, and particularly so in Central and Eastern European countries.

Adding climate- and air pollution-based components to the minimum energy taxes strengthens the contribution of the price effect, in line with the shifting firms-households balance in emission reductions and additional tax revenue. While in the *Energy* scenario the price effect explains about 55% of the total household welfare losses, this share increases to 59% and 63% in the *Climate* and *Air* scenarios, respectively. The current country-level tax base and rate, the fuel mix, and the share of (energy) expenditures in income are the key factors driving the heterogeneity of the price effect across countries. For the income effect, the characteristics of sectors affected by the ETD reform play an important role, such as exemptions in current taxation, their weight in the overall economy and in total employment, the importance of energy in the production process, the ease of enhancing energy efficiency and the possibility to substitute towards other sources of energy.

In the following sections, we explore the distribution of these aggregate welfare effects across households.

3.2. Within-country inequality and poverty

In this section, we assess the socio-economic consequences of the proposed tax reforms by means of commonly used synthetic indicators for inequality and poverty, the Gini coefficient and the at-risk-of-poverty rate (AROP). The Gini is based on household-level incomes (equivalised with OECD modified equivalence scales) and is shown on horizontal axis of the four panels displayed by Figure 3. The AROP rate indicates the share of people with equivalised incomes below 60% of the median income in the baseline, and is shown on the vertical axis of Figure 3. We distinguish between price (panel a) and income effects (panel b), and compare the total effect before (panel c) and after revenue-recycling transfers (panel d).

For most countries, the results of the micro-simulation analysis indicate an inequality-increasing price effect that is modest in the *Energy* and *Climate* scenarios, and somewhat stronger in the *Air* scenario. Typically, expenditure shares for residential energy decline with income, while energy expenditure shares for private household transport show an inverse U-shaped pattern over the income distribution. As a result, the impacts on inequality roughly track the price changes presented in panel c of Figure 2. Countries with a substantial increase in residential energy prices, such as Croatia, Hungary, and Poland, experience a comparably strong increase in inequality. In two countries, Bulgaria and Romania, the price effect is inequality-decreasing as progressive transport fuel taxation (see, e.g, Amores et al., 2023) compensates the inequality-increasing effect of the price rise in residential energy. In line with results on emissions, prices and tax revenue presented above, the *Air* scenario shifts the burden more towards households and residential energy, explaining the stronger effects on inequality.

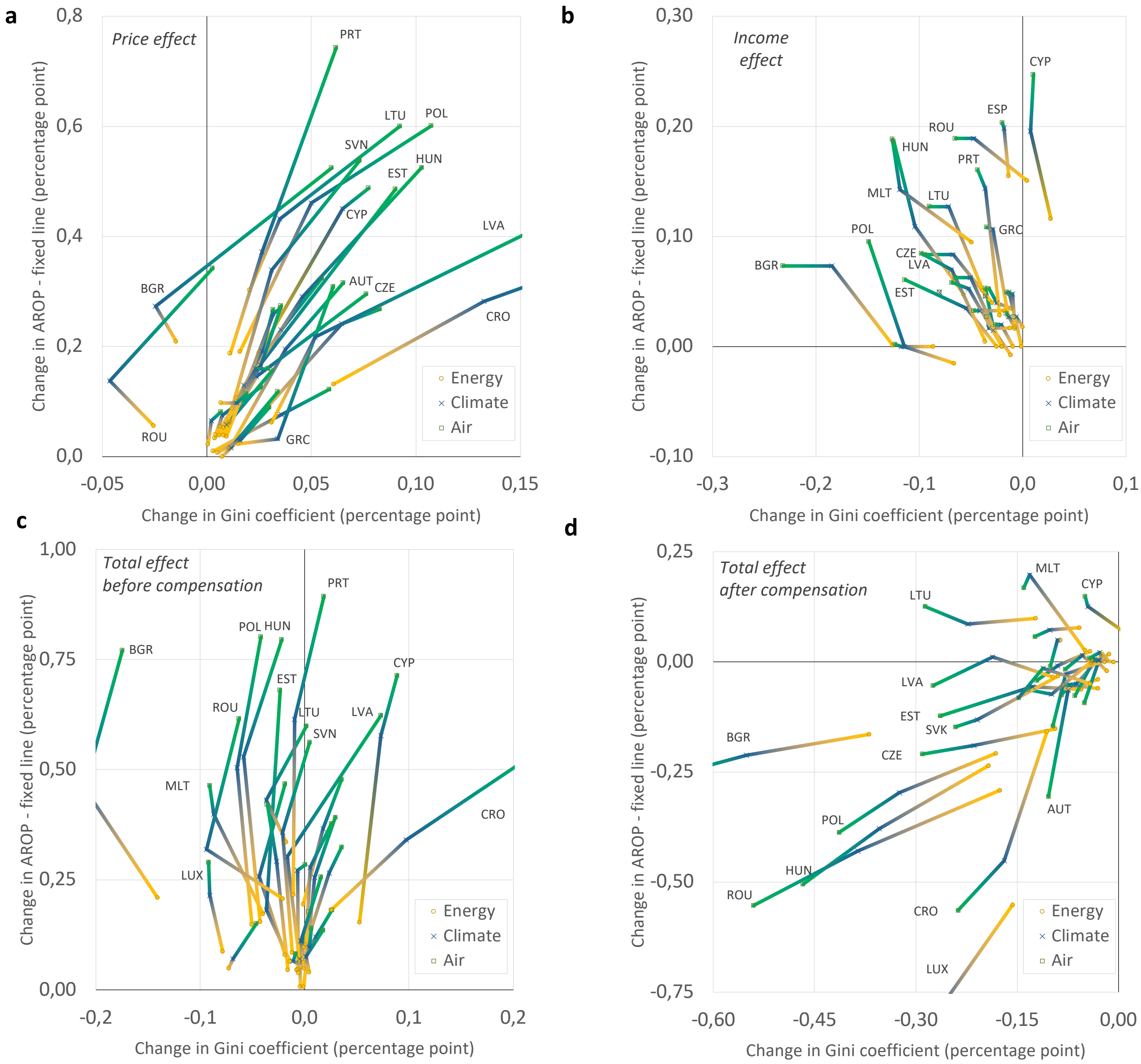

Figure 3. Impacts on inequality and poverty across countries and scenarios.

In contrast with the price effect, results indicate an inequality-reducing income effect (panel b of Figure 3). The decline in labour and capital income disproportionately affects the middle and top of the income distribution, as households at the bottom of the income distribution rely more on pensions, unemployment benefits and other government transfers. This inequality-reducing income effect tends to be larger in countries with stronger wage reductions (panel b of Figure 2). Two additional factors that determine the income effect on inequality is the employment share of affected sectors (mostly the transport sector) and the position of the workers in these sectors in the income distribution. The proposed reforms have the largest inequality-reducing income effect in Bulgaria, where increases in effective tax rates are relatively strong in the transport sector, and where transport sector workers represent a comparably large share of the workforce and are more concentrated towards the higher end of the income distribution (see Figure SI-9 in Appendix B). Note that we assume here that social welfare benefits are not indexed to consumption prices or wages, which would influence distributional outcomes (see Vandyck et al., 2021). Furthermore, these results should be interpreted as short-term impacts, as the distributional assessment ignores household-level labour supply decisions, including adjustments at the external margin of the labour market and labour mobility across sectors, jobs, and countries. Empirical work has shown that these considerations can increase the regressivity of income effects from environmental policy (Vona, 2023).

Combined, the price and income channels lead to mixed inequality impacts across countries and scenarios (panel c, Figure 3). Generally, the changes in Gini coefficient are small, and outliers appear on both the positive and the negative side. Once we factor in within-country revenue recycling of additional tax revenue (obtained from households) through a (uniform per capita) lump-sum transfer (panel d), the proposed energy tax reforms reduce within-country inequality, particularly in low-income countries in the EU. Overall, these results illustrate that regressive effects arise in some countries, and that they can be offset by compensatory measures.

A more consistent pattern across countries emerges in terms of changes in poverty. Both price and income effects (panels a and b of Figure 3) contribute to a modest increase in AROP rates compared to the baseline.[12] As in the case of inequality, lump-sum revenue recycling largely overturns these poverty impacts. In a few countries, however, the lump-sum transfer is insufficient to fully offset the poverty-increasing effects of higher prices and lower incomes, such that a minor increase in AROP rate remains after revenue recycling. Although the impact is small, recycling schemes that better target the poor than equal-per-capita transfers would be needed to decrease poverty in these instances.

3.3. Within-country welfare effects across population groups

The Gini coefficient and the AROP rate provide a useful first indication of the distributional impacts, but fail to reveal the impact heterogeneity (see, e.g. Jenkins, 2009) over the income distribution (vertical equity) and across households with similar income but different socio-economic and demographic characteristics (horizontal equity). In this section, we explore vertical and horizontal equity impacts in more detail.

Vertical equity impacts are shown in panels a-d of Figure 4, which present the (unweighted) average across country-level deciles of the price and income effects on welfare (panels a and b), and of the total welfare effect without and with lump-sum revenue recycling (panels c and d, respectively). The use of unweighted averages is motivated by the focus on within-country distributional effects in this section and implies that the average impacts for the bottom deciles in different countries receive equal weight regardless of the corresponding level of income and population size.

As before, the price effect of the ETD reform scenarios is regressive while the income effect is progressive. The price effect is relatively strong for the first decile. From the second decile onwards, total welfare impacts before transfer (panel c) show a somewhat progressive pattern that is roughly similar across scenarios. The main difference when moving from the *Energy* to the more ambitious (*Climate* and *Air*) scenarios comes from the order of magnitude. In line with what we discussed in the previous sections, we can see that a stronger price effect in the *Air* scenario results in a slightly flatter impact pattern over deciles two to ten. Once we account the recycling of additional tax revenue via lump-sum per capita transfers, the impact pattern changes completely (see panel d, Figure 4). The welfare losses of the bottom three deciles are more than offset, on average, resulting in net welfare gains with respect to the baseline (up to 1.3% in the *Air* scenario). On the contrary, the welfare impacts after transfers remain negative for the top income deciles (up to -0.8% in the *Air* scenario).

By averaging across deciles in all EU countries, these results provide a useful first glance of distributional impacts. At the same time, these figures conceal the heterogeneity (across countries) in impact patterns across deciles within countries. Figure SI-10 displays the range of the decile-average welfare effects across the EU-27 countries, illustrating that the average welfare impacts of the bottom decile range from slightly negative (welfare loss) to about +5% (in the *Air* scenario in Romania). At the opposite end, the welfare impact experienced by the top decile ranges from approximately zero (e.g. in the Netherlands, *Energy* scenario) to -2.6% (in Bulgaria, *Air* scenario).

In addition to impact heterogeneity across income groups, welfare effects can vary substantially within income groups, as households of similar income differ in expenditure patterns and income sources. These horizontal equity effects are important to consider, including for a better view on acceptability concerns of energy price reform (Douenne, 2020; Cronin et al., 2019). The within-decile welfare impact dispersion can be clearly appreciated in the country-specific boxplots in Figures SI-11 to SI-13 in Appendix B and is particularly large at the lower end of the income distribution. While on average (and median) we see that in most countries the first and second deciles are better-off after the lump-sum transfer, this is not true for all households classified in this income group. The finding that households at the

[12] The only two exceptions are Austria and Poland in the Energy scenario, where the AROP rate slightly decreases after the income shock due to interactions with the tax-benefit system. For a small group of households that are close to the poverty threshold, the downward shift in labour income increases means-tested benefits and, correspondingly, household disposable income.

bottom end of the income distribution (including in the first decile) experience adverse welfare effects after the reform (also after the lump-sum transfer) suggests that more targeted measures might be needed to compensate vulnerable households that are particularly exposed to the energy price changes induced by the ETD reform scenarios.

The household-level microdata enables a further exploration of impact heterogeneity along other (non-income) socioeconomic characteristics of households and individuals. Figures SI-14 and SI-15 in Appendix B show the welfare effects in the *Energy* scenario by economic activity status (e.g. employed, unemployed, pensioners) and by age-gender groups, respectively. We plot the inter-quartile distribution of the total welfare effect for each of these groups before and after the lump-sum revenue recycling transfer. As our analysis accounts for income effects through wage changes, employed people tend to experience more negative welfare impacts than unemployed and pensioners (for which we assume that pensions and unemployment benefits are not indexed to prices or wages). The above-average adverse welfare effects experienced by children/students is due to a household composition effect: these groups tend to be over-represented both in households with employed adults as well as in the bottom deciles of the income distribution, where the price effect tends to be stronger. These composition and income effects also imply lower welfare losses for older people (over 65) and women, although we do not find a significant gender component in the results.

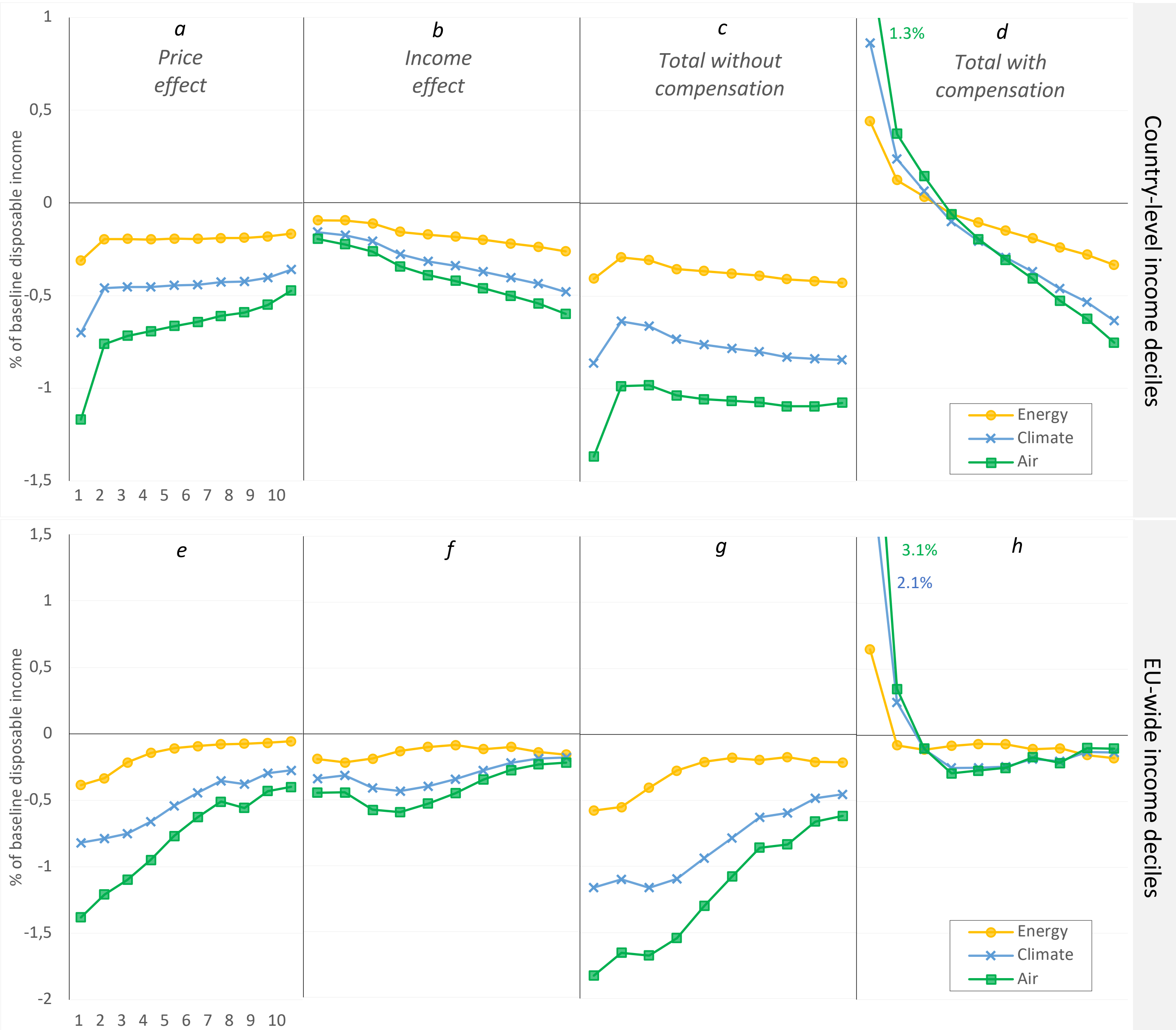

Figure 4. Price, income and total welfare effects by decile across scenarios. a-d, Welfare effect averaged over country-level income decile impacts. e-h, Average welfare effect per EU-wide income decile.

We can furthermore look at welfare impacts for households in energy poverty, where we use the 2M indicator to identify people in energy poverty if they live in a household with an income share of residential energy expenditures which is above twice the national median. For the majority of countries (across scenarios), the energy poor experience larger welfare losses than those not in energy poverty before accounting for the revenue recycling transfer (Figure SI-16 in Appendix B). This is mainly due to a stronger price effect, as the group of households in energy poverty is characterized by large residential energy expenditures relative to income. For the *Energy* and *Climate* scenarios, results for about half of all EU countries indicate that the energy poor experience more negative impacts before transfer, but more positive welfare impacts from tax reform after the lump sum transfer, compared to those not in energy poverty. In the *Air* scenario, which results in stronger residential energy price increases (Figure 2), households in energy poverty face stronger welfare losses than non-energy poor in all countries (except Luxembourg) before transfer, and in 17 countries after transfer of additional revenue.

3.4. Within- and between-country distributional effects

The results in the previous sections illustrate that impacts of proposed energy tax reforms differ across countries (Section 3.1) and across households within countries (Sections 3.2 and 3.3). In this section, we combine both dimensions by pooling all EU households and ranking them according to their baseline equivalised household disposable income, adjusted by purchasing power parity levels.[13] The resulting EU-wide income distribution offers a useful base to assess distributional impacts at the EU level. In this distribution, more than two thirds of the poorest 10% and 50% of the second decile are individuals residing in Poland or Romania. In deciles 4 to 8, more than two thirds reside in Spain, Italy, Germany, or France. In the top income deciles (9th-10th), about 50% are individuals in France or Germany, and the rest in other smaller Western or Northern European countries (see Appendix B, Figure SI-17).

Panels e-h of Figure 4 are analogous to panels a-d of the same figure, but for EU-level income deciles instead of country-level deciles. Total welfare effects (panel g) before revenue recycling transfer for the poorest 20% of the EU population indicate an average welfare loss of more than 0.5%, 1% and 1.5% of baseline disposable income for the *Energy*, *Climate* and *Air* scenarios, respectively. Importantly, these welfare losses generally decline with income, which indicates that jointly accounting for within- and between-country heterogeneity leads to a regressive impact pattern. A comparison with the results that focus on within-country distributional impacts (panel c of Figure 4) suggests that cross-country impact differences are an important source of regressivity for the ETD reform scenarios.

The price and income effects (panels e and f) reveal that the regressivity of the price effect is not compensated by a progressive income effect when considering the EU-wide income distribution. Stronger regressivity in the price effect when considering between-country differences confirms recent findings by Feindt et al. (2021) in the context of carbon pricing. More significant changes, however, occur in the income-side impact pattern (not included in Feindt et al., 2021). Unlike the results illustrating country-level impacts (panel b), the welfare losses via the income channel are now more concentrated towards the bottom end of the income distribution. As EU countries with relatively low income tend to have higher energy- and emission-intensive economic activity and lower energy tax rates, revised EU energy tax floors lead to regressive wage (see Figure 2) and income-side welfare impact patterns at the EU level, reflecting the heterogeneity across countries. Earlier model-based studies based on a coarse labour market representation, such as Landis et al. (2021) and Mayer et al. (2021), find progressive impacts of carbon pricing due to the sources-side impacts, while empirical findings suggest regressive sources-side impacts (Vona, 2023). Our results suggest that considering heterogeneity across space and sectors (here disaggregated by 27 countries and 6 sectors) can result in regressive sources-side (income) impacts, providing a potential bridge between diverging results in modelling and empirical studies.

When additional tax revenue is recycled (within the country) via lump sum transfers, the regressivity of the reform at the EU-wide level (panel g) is completely reverted (panel h). Compared to the results after transfer that focused on within-country distributional impacts (panel d), the welfare gains are now larger for the first decile, but also more concentrated towards the bottom of the income distribution. Decile-average impacts from the third EU-level income

[13] We use Eurostat's publicly available PPS series from 2019.

decile onwards are slightly negative across all scenarios. Per-capita transfers are uniform within a country but differ across countries, resulting in a non-monotone impact pattern after transfers.

As in the case of within-country distributional effects, average welfare effects per EU-wide decile hide substantial heterogeneity across households in the same income group (Figure SI-18 in Appendix B). The welfare effect before transfer in the bottom two deciles (i.e. poorest 20% of the EU population) ranges between -1.5 to 0.8% in the *Energy* scenario, from -3% to 1% in the *Climate*, and from -4.2% to 1.8% in the *Air* scenario. In addition to heterogeneity across household characteristics in dimensions other than income, these horizontal equity impacts are now also due to the fact that EU-wide deciles pool individuals living in households with similar incomes but residing in different countries. Differences in existing tax rates across countries therefore contribute to the impact dispersion within EU-wide deciles. While on average the first decile is better off after revenue recycling via lump sum transfer to households, about 25% of the poorest decile still experiences a welfare loss after transfer.

3.5. Discussion: Green and fair?

One of the overarching questions of the paper is whether proposed energy taxation reforms are aligned with a just transition to climate neutrality. Whereas the previous sections discussed environmental and distributional impacts separately, Figure 5 plots CO_2 emission reductions directly against indicators of fairness (poverty in panel a, inequality in panel b). This summarizing figure highlights the consistent findings across countries (1) that the ETD reform introduces a trade-off between emission reductions and an increase in poverty, when no compensatory measures are taken (panel a), and (2) that revenue recycling can jointly reduce emissions and income inequality within countries, highlighting the potential for synergies across social and environmental dimensions.

At the same time, the findings in previous sections also illustrate that a lump-sum per capita transfer based on the additional taxes collected from the household sector is not sufficient to compensate all individuals in the bottom and middle-income groups at either the country or EU-wide level, as results reveal a large impact spread within income groups. These horizontal equity impacts are important to consider in a broader context of societal acceptability of policy reforms (van der Ploeg et al., 2022; Vandyck et al., 2022). Our results indicate more negative impacts for workers, suggesting that complementary labour market policies (e.g. employment transition programs, re-skilling, upskilling) could play a role in cushioning distributional concerns. The results also show that households in energy poverty risk negative welfare losses in the absence of compensatory measures, indicating that energy poverty concerns require dedicated policy responses (Vandyck et al., 2023).

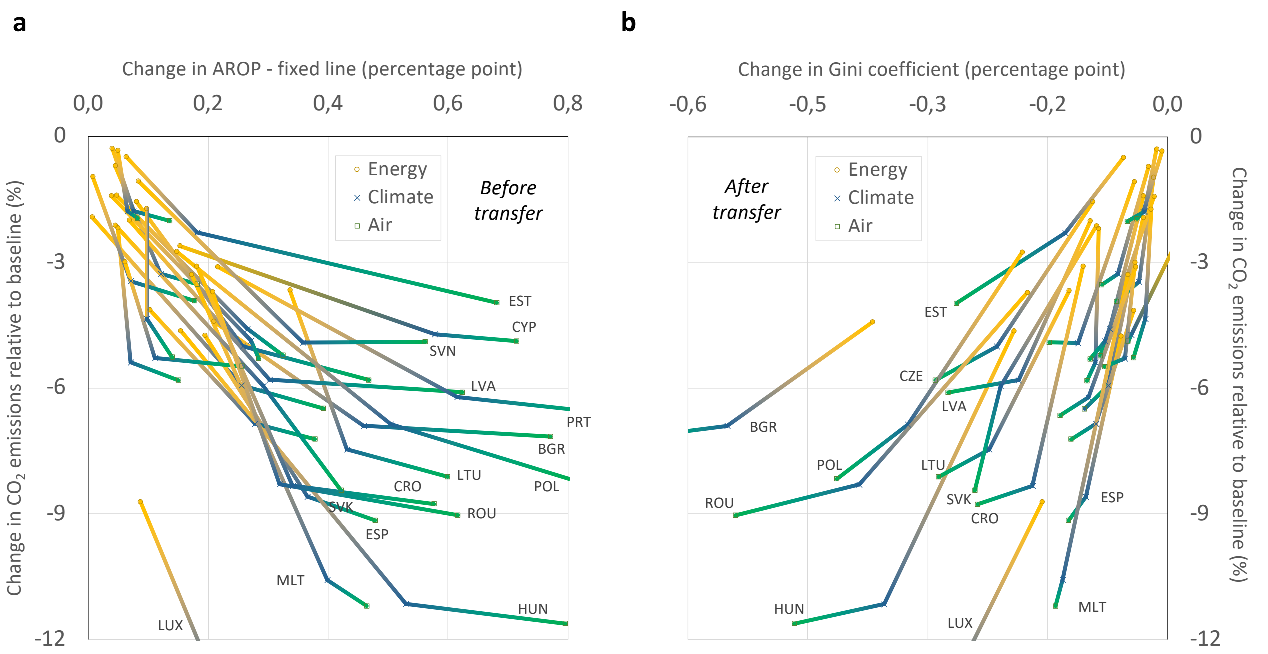

Figure 5. Selected social and environmental outcomes. a) CO_2 emission reduction vs. poverty increase before transfer, b) CO_2 reduction vs. inequality decrease after transfer

Broader policy packages could consider more targeted transfers, social tariffs, as well as other instruments, such as means-tested subsidy schemes (Hänsel et al., 2022). While alternative revenue recycling schemes are beyond the scope of this paper, earlier work illustrates the potential of earned income tax credits in addressing equity concerns of carbon pricing (Cronin et al., 2019). However, the same composition effect that drives the progressivity of the income effect in our analysis (i.e. the under-representation of workers at the bottom of the income distribution) suggests that compensatory measures based on labour taxes will do little to cushion the inequality-increasing effect of the price channel for people not earning an income from labour.

A broader policy package can also consider careful sequencing of policy measures. A timely phase-in of subsidies and taxes potentially limits the exposure of vulnerable households to strong price effects by enhancing energy efficiency and shifting to low-carbon sources of energy. This paper illustrates the importance of policy sequencing for distributional impacts: strong climate policy measures (in the baseline and via CO_2-based energy taxes) can lead to a shift towards biomass for residential heating; then, introducing air pollution-based taxation that raises the cost of biomass use gives rise to regressive impacts as residential energy expenditures decline with income. A joint consideration of multiple environmental externalities together with equity considerations is therefore important to avoid socio-political lock-in effects that prevent reflecting air pollution damages in the pricing of energy.

Moreover, we have identified substantial cross-country impact heterogeneity, which is relevant from the point of view of the ongoing convergence and territorial cohesion challenges in the EU, as well as for political economy reasons. At the same time, our analysis disregards other regional policy initiatives and dedicated policies to support regions in transition, such as the Just Transition Fund. In addition, our assessment ignores potential benefits from avoid climate damages and improved air quality, and the associated economic gains (Dechezleprêtre et al., 2019).

4. Conclusions

To deliver on the proposed greenhouse gas emissions reduction target of net 55% by 2030, the EU proposed a series of legislative initiatives in the Fit-for-55 Package. These initiatives include the revision of the Energy Taxation Directive (ETD), which aims at revising the minimum taxation levels of energy products across EU countries. While getting energy prices right – reflecting externalities and reducing fossil fuel subsidies – can facilitate a transition towards sustainable energy use, tax reforms often face acceptability challenges related to equity concerns within and between countries.

We combined economy-wide and household-level modelling to study the environmental and distributional impacts of incremental changes in the existing legislation for energy excises in the EU. After capturing the details of current energy tax systems, we quantify three scenarios based on the European Commission's reform proposal: an *Energy* scenario with minimum tax rates according to energy content, a *Climate* scenario which adds a CO_2-based component, and the *Air* scenario which further adds a tax component reflecting the health damages from air pollution.

Our results show that the revision of the ETD is expected to have an important positive environmental impact. We find that expanding the tax base and reforming the rates to reflect energy content yields benefits for climate and clean air. In countries like Poland, Hungary, Bulgaria, and Romania, reductions of CO_2 in the *Climate* scenario are estimated in the range 7-11%, with larger numbers for $PM_{2.5}$ emission reductions in the *Air* scenario (compared to current-policy projections). Results indicate largely synergistic environmental effects, as climate-based taxation reduces air pollutant emissions, and air pollution-based taxation tends to strengthen climate change mitigation (despite trade-offs at a more granular level).

In terms of socio-economic outcomes, the reforms lead to higher energy prices and lower labour income, causing heterogeneous distributional impacts within and across countries. Within countries, regressive price effects are (partially) counterbalanced by progressive income-side changes. Accounting for between-country heterogeneity results in a more regressive price effect and turns the income-side impact channel into a regressive one. In both cases (country- and EU-level), the household groups with lowest incomes can be made better off on average than before the reform by recycling additional tax revenue through lump sum transfers. The analysis thus suggests that careful policy design can pursue environmental and social targets at the same time, reducing greenhouse gas emissions, air pollution, poverty, and inequality simultaneously.

Yet, lump sum transfers leave large impact heterogeneity within income groups unaddressed. Further exploring policy approaches that tackle horizontal equity concerns is an important avenue for future research. Our findings on cross-country equity are also important for political acceptability, as revisions of the Energy Taxation Directive need to be agreed with a unanimity of votes in the Council of the European Union.

While capturing a large set of countries and environmental and distributional impacts, the analysis only looks at a selected set of policy instruments. Other elements in a policy package can help ensure a just transition to climate neutrality. For the proposed ETD revision, in particular, exemptions (up to the minimum rates) and a transition period for household heating fuels and for energy use of vulnerable households can ease the potential regressive impacts. More broadly, equity dimensions are also included in the Effort Sharing Regulation, the Just Transition Mechanism and the Social Climate Fund. Furthermore, national, and subnational subsidy schemes and dedicated policies can help address related issues such as energy poverty, and labour market policies can facilitate the transition of workers to ease the potential distributional impacts arising from the sources side. From a modelling perspective, representing broader policy packages, as well as imperfect labour mobility across space and sectors, provide valuable research directions. Other externalities, such as road congestion, could also be considered in future work.

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Authorship contribution statement

Sofia Maier: Formal analysis, Writing, Methodology
Toon Vandyck: Conceptualization, Formal analysis, Writing, Methodology, Supervision
Mattia Ricci: Formal analysis, Methodology
Luis Rey: Formal analysis, Methodology
Marie Tamba: Formal analysis, Methodology
Fabian Wagner: Methodology

Declaration of competing interest

The authors declare no conflict of interest.

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