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Who bears the burden of greening electricity?

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A B S T R A C T

Faced with the threat of climate change many countries are promoting renewable energies to decarbonize their energy system. A common policy to foster electricity from renewable energy sources are feed-in tariffs which are financed by surcharges on electricity prices. Higher electricity prices in turn raise concerns on regressive distributional impacts. In this paper, we investigate the distributional impacts of three alternative policies to subsidize renewable energy production in Spain: (i) exemptions from the electricity surcharge for residential consumers, (ii) an increase in mineral oil taxes, and (iii) an increase in value-added taxes. We find that all three options can attenuate the regressive distributional effects compared to feed-in tariffs. For our quantitative impact assessment, we couple a microsimulation model with a computable general equilibrium model to capture the incidence on heterogeneous households in an economy-wide framework.

1. Introduction

The promotion of renewable energy ranks high on the policy agenda of many governments around the world. The main reason is the need for rapid decarbonization of the energy system to cope with climate change (IRENA, 2020). Renewable energy deployment is growing rapidly (IRENA, 2019, 2020b), especially in electricity generation which is (still) the primary source of CO_2 emissions for many countries. Greening electricity is central to the transition towards a low-carbon economy, as electricity from renewable energy sources (RES-E) can replace fossil fuels in other sectors of the economy such as heating, cooling, and transportation. The European Union constitutes a prime example of substantial renewable energy penetration in the electricity system. In just one decade, the share of RES-E increased from 14.8% in 2005 to 28.8% in 2015 (Eurostat, 2017) and must continue to increase to meet the EU's ambitious 2030 renewable energy targets (EC, 2018).[1]

However, with the massive penetration of RES-E, there is also growing concern about the rise of electricity prices, especially with regard to the incidence for low-income households (Mastropietro, 2019). Although the cost of renewable power generation – in particular wind and solar PV – has dropped significantly in recent years rendering RES-E competitive with fossil fuel-based electricity generation in many countries (IRENA, 2019), the price of electricity is still affected by generous subsidies to *extant* renewables that are guaranteed for many years to come. This applies to technology-specific feed-in tariffs (FITs) which have historically been used as a key regulatory instrument for RES-E support. FITs typically combine a long-term fixed price for RES-E producers with the obligation for grid operators to purchase all the electricity generated from renewable energy sources. The differences between FITs and the (lower) wholesale electricity price imply subsidies to renewables which may be financed by a surcharge included in the retail electricity price (CEER, 2017). Such surcharges have contributed electricity price increases for households in recent years – especially in countries such as Germany or Spain with very generous FITs[2] –undermining the societal acceptance of RES-E support policies. Against this background, the economic incidence of RES-E promotion and the question how this incidence may change under alternative financing options have received considerable attention among researchers and policymakers (e.g., Schmalensee, 2012, Neuhoff et al., 2013, del Río and Mir-Artigues, 2014, Mir-Artigues et al., 2015, or Böhringer et al., 2017).

Literature surveys on the incidence of climate and energy policies (see, e.g., Fullerton, 2008) mostly find regressive impacts due to

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[1] On June 14, 2018, the EU Commission, the EU Parliament, and the EU Council reached a political agreement, which includes a binding renewable energy target for the EU in 2030 of 32% in final energy consumption (EC, 2018). For comparison, the share of renewables in EU final energy consumption in 2015 was around 16%.

[2] For analyses of how RES-E support schemes affect retail electricity prices see e.g. del Río et al. (2018).

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increased fuel cost, which represent a higher expenditure fraction for low-income groups than for high-income groups (expenditure channel). In addition, non-fossil fuel options are often more capital-intensive than fossil fuel options, causing firms to demand more capital relative to labor and thereby reducing wage income as the primary source of revenue for low-income groups (income channel) (Fullerton, 2008). The regressive impacts of RES-E promotion financed by electricity surcharges were confirmed in an empirical analysis for Germany. Using household micro data, Neuhoff et al. (2013) show that the burden of the German RES-E surcharge is significantly higher for low-income groups. They propose three options to mitigate the regressive policy impacts: (i) a reduction in the general sales tax on electricity, (ii) increased support for energy efficiency measures, and (iii) the payment of additional lump-sum transfers to low-income groups. Böhringer et al. (2017) combine a microsimulation model with a computable general equilibrium model to study the incidence of RES-E policies in Germany. They find that the regressive impacts of the German RES-E promotion could be significantly mitigated by (i) harmonizing feed-in tariffs across all RES-E technologies, (ii) removing exemptions for industry from the electricity surcharge, or (iii) broadening the subsidy base towards general consumption (i.e., value-added taxation) instead of electricity consumption only.

In this paper, we examine the incidence of RES-E policies in Spain accumulated over the period 2004–2017 and propose reforms in financing RES-E subsidies that are less regressive. Spain provides a policy-relevant case study because it has implemented a strong support scheme through FITs that has significantly increased RES-E but has also contributed to a significant increase in domestic electricity prices. In our analysis, we investigate how three alternative financing schemes of the Spanish FITs affect the incidence on households: (i) an exemption from the electricity surcharge for residential consumers, (ii) an increase in mineral oil taxes, and (iii) an increase in value-added taxes. We find that all three options can mitigate the regressive distributional effects compared to feed-in tariffs. In this vein, our analysis provides guidance for policy reforms aimed at mitigating the regressive impacts of RES-E promotion. We draw our insights from numerical simulations with coupled computable general equilibrium (CGE) and microsimulation (MS) models using empirical data for Spain. The combined CGE-MS analysis has the appeal that it quantifies the incidence of policy regulation across heterogeneous households through the expenditure and income channels in an economy-wide framework.

The remainder of this paper is organized as follows. Section 2 provides background information on RES-E promotion policies in Spain. Section 3 summarizes the basic structure and parameterization of the coupled CGE-MS models. Section 4 presents the policy scenarios and discusses the simulation results. Section 5 concludes.

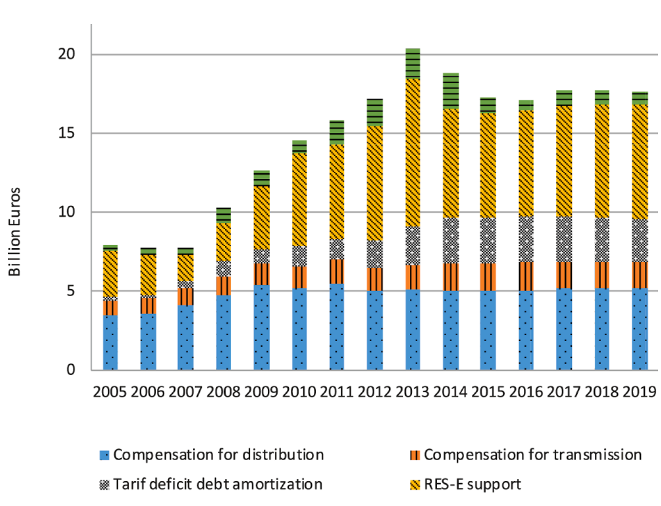

Fig. 1. Annual regulatory cost (bn €) in the Spanish electricity system (2005–2019).

2. RES-E promotion in Spain

Historically, the promotion of renewable energy in Spain was triggered by the goal of reducing the country's heavy import dependence on fossil fuels. In the last decade, concerns on climate change became the main argument for renewable support policies. The share of RES-E in Spain has almost doubled in 15 years, from 19.1% in 2005 to 36.8% in 2019, mainly due to the massive expansion of wind and PV power plants (Eurostat, 2017) – consequently, Spain has achieved its national target of having renewable energy account for 20% of gross final energy consumption by 2020.[3] RES-E promotion policies have contributed significantly to this development. The RES-E support scheme in Spain built on feed-in tariffs (FITs), already introduced in 1998, which had been financed by an electricity surcharge paid by electricity consumers.

Fig. 1 shows the dominant share of RES-E subsidies in the regulatory cost of the Spanish electricity system. Between 2005 and 2019, annual RES-E subsidies increased in nominal terms from €2.9 billion to €7.2 billion (CNMC, 2020). Despite recent regulatory changes in 2017[4] towards auctioning newly installed RES-E capacities, the cost for extant RES-E capacities financed via the electricity surcharge is not expected to decrease before 2030, as these subsidies are linked to the lifetime of wind and PV power plants, which is between 20 and 30 years.

The high subsidies for RES-E promotion, financed by an electricity price surcharge, led to a significant increase in Spanish electricity prices. More specifically, the average annual electricity price for a medium-sized household more than doubled in the decade from 2005 to 2015 (from €0.109 to €0.23 per kWh) and increased by almost two-thirds for a medium-sized industry (from €0.068 to €0.111 per kWh).

Higher electricity prices are in particular a problem for low-income households. Fig. 2 shows electricity cost as percentage of consumer expenditures for twenty income groups (ventiles) between 2002 and 2013, using data from the Spanish Households Budget Survey (INE, 2018a). Electricity expenditures as a share of disposable income increased from 3.7% in 2002 to 5.5% in 2013 in the lowest income group (first ventile) and from 1% to 1.5% in the highest income group (twentieth ventile) over the same period.

3. Method of assessment: models and data

3.1. Models

For our quantitative incidence analysis, we combine a computable general equilibrium (CGE) model with a microsimulation (MS) model. The combined CGE–MS framework provides an economy-wide perspective that accounts for policy-induced changes in commodity prices (expenditure channel) and factor prices (income channel). At the same time, the integrated system captures the heterogeneity of households in their expenditure and income patterns, allowing for detailed incidence analysis.

3.1.1. Computable general equilibrium (CGE) model

CGE models combine data from input-output tables with

[3] The share of renewable energy in gross final energy consumption increased from 12% in 2005 to 17% in 2015 and to 21,4% in 2020. Accomplishment of Spain's national target was favoured by the COVID-19 crisis – without the latter the RES-E share has been estimated to be slightly below the 20% target level (Rodriguez-Zuñiga et al., 2021).

[4] In our analysis, the surcharge refers to the financial support guaranteed for the lifetime of 2004–2017 RES-E projects. The capacity auctions during 2017 were allocated without any public support as renewables (onshore wind and solar PV) became competitive in Spain. Under the current regulation such as the Royal Decree-15/2018 for self-consumption of electricity and the Royal Decree-Law 23/2020, which establishes a new auction mechanism based on the power delivered to the electricity system, future installations of renewables are no longer expected to increase the surcharge prevailing until 2030.

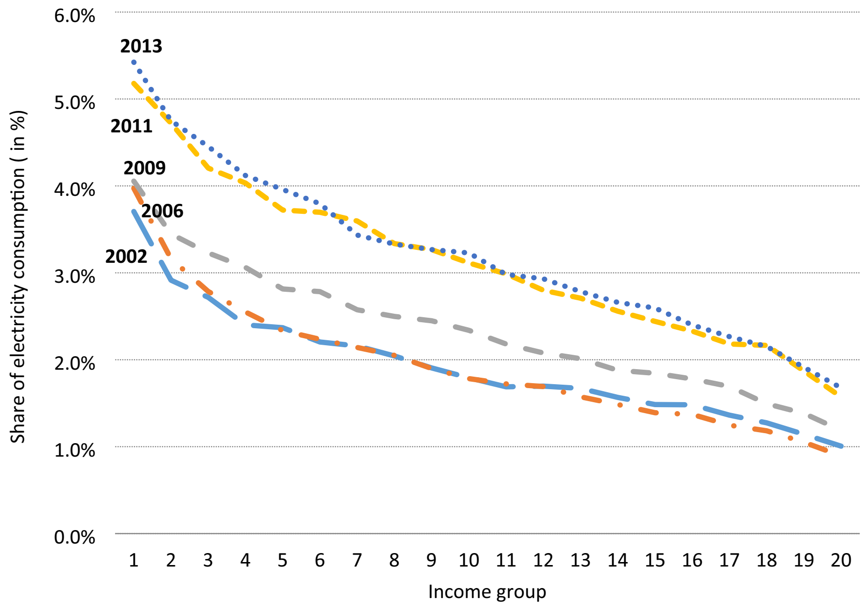

Fig. 2. Annual expenditure (in % of total)) on electricity by income group.

assumptions about market structure and elasticities that determine how strongly market supply and demand respond to price changes. They are well established in applied economic analysis to assess the outcome of how the economy adjusts to policy interventions. For our quantitative impact assessment, we use standard static multi-sector open-economy CGE model calibrated to Spanish data (Böhringer et al., 2019). Below, we provide a brief non-technical summary of the basic model structure (for algebraic details of the core model logic, see Böhringer et al., 2015).

The production of commodities other than fossil fuels and electricity is represented by nested constant-elasticity-of-substitution (CES) cost functions that describe the price-dependent use of capital, labor, energy, and material in production at three levels. At the top level, a CES composite of intermediate material is priced against an aggregate of energy, capital, and labor. At the second level, a CES function describes the substitution possibilities between intermediate demand for the energy aggregate and a value-added composite of labor and capital. Finally, at the third level, a CES function captures the substitution possibilities between capital and labor within the value-added composite, while various energy inputs (coal, gas, oil, and electricity) enter the energy composite subject to a CES. In the production of fossil fuels, all inputs except the sector-specific fossil fuel resource are aggregated in fixed proportions; this aggregate trades off with the sector-specific fossil fuel resource at a CES. To represent RES-E production, we break down the electricity sector into two composite production technologies: conventional electricity generation and renewable electricity generation. These two electricity generation technologies produce electricity by combining technology-specific capital with labor, fuel, and material inputs. Electricity generation technologies respond to changes in electricity prices according to technology-specific supply elasticities. Electricity from different electricity generation technologies is treated as a homogeneous good.

Final demand for consumption is determined by a representative household which maximizing utility subject to a budget constraint with fixed investment (savings). The representative agent receives income from three primary factors: Labor, capital, and fossil fuel resources (coal, gas, and crude oil). Labor and capital are mobile across sectors. Fossil-fuel resources are fixed to the respective fossil-fuel production sectors. Final consumption is formed as a CES aggregate of composite non-energy consumption and composite energy consumption. Both the non-energy consumption bundle and the energy consumption bundle are themselves CES functions of more disaggregated non-energy and energy goods.

The government levies taxes to finance transfers and the provision of a public good. The public good is produced with goods purchased at market prices. In all policy simulations, the level of provision of the public good is held constant such that there is no need to trade off private consumption and public consumption (assuming separability) in our cost-effectiveness analysis of alternative RES-E financing options. The revenue-neutral provision of the public good is ensured through lump-sum transfers between the government and households.

Bilateral trade is based on product heterogeneity, with domestic and foreign goods distinguished according to their origin (Armington, 1969). A balance of payment constraint incorporates the trade deficit or surplus of the base year. All goods used in domestic intermediate and final demands correspond to an Armington composite which combines domestically produced goods and the imported goods of the same variety at a constant elasticity of substitution.

3.1.2. Microsimulation (MS) model

The MS model characterizes households by their income from factor endowments and transfers (income channel). It also describes how households spend their disposable income after savings decisions across different consumption categories (expenditure channel). The core of the MS model is an econometrically estimated demand system which captures price-responsive behavior through own-price, cross-price, and expenditure elasticities. We use the wide-spread Almost Ideal Demand System (AIDS) proposed by Deaton and Muellbauer (1980) to estimate household-specific demands for nine consumption categories including: Food & Beverage, Housing, Fuel, Electricity, Heating, Public Transport, Education & Leisure, Durables, and Other Goods & Services. Appendix A includes a detail algebraic description of the AIDS model together with regression results for elasticities, our data sources, and also a discussion of the limitations of our regression approach.

3.1.3. Coupling of CGE and MS models

The CGE and MS models are iteratively linked based on the decomposition method presented in Rutherford and Tarr (2008). We first run the CGE model with a single representative household in order to evaluate policy impacts on the prices for consumption goods and factors of production. The MS model determines consumption responses due to

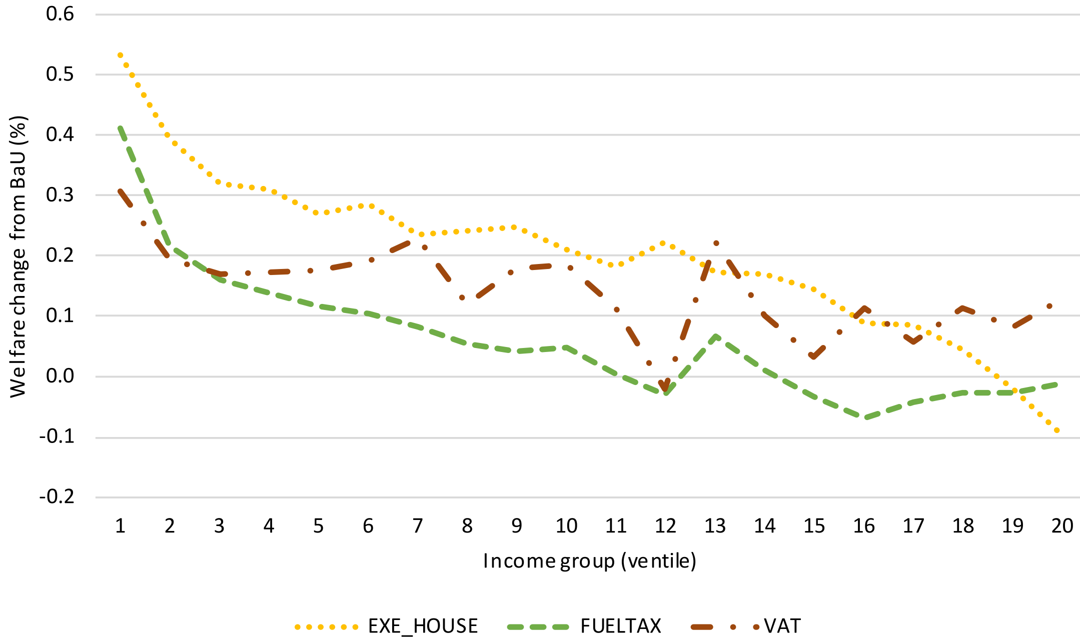

Fig. 3. Welfare effects by income group (% of HEV in income).

changes in commodity prices (expenditure channel) and factor prices (income channel) generated by the CGE model. Based on the MS results, the preferences of the representative household in the CGE model are recalibrated in line with the aggregate demand response across all the different households in the MS model. The CGE model is then solved again with the recalibrated expenditure function of the representative household and then returns commodity and factor prices to the MS model for the next iteration. This coupling algorithm is repeated until the two models converge towards an overall consistent equilibrium solution. Effectively, the coupled models produce identical results to a stand-alone CGE model with explicit inclusion of all heterogeneous households. The combined CGE–MS approach, however, has the advantage of being more numbering tractable and requiring less computer processing time, given the large number of households in our income-expenditure survey.

3.2. Data

For the parameterization of the CGE model, we follow the standard calibration procedure in applied general equilibrium analysis. The base-year input-output data determine the free parameters of the cost and expenditure functions such that the economic flows represented in the data are consistent with the optimizing behavior of the economic agents. We use the Spanish input–output table for 2014 (INE, 2018b). Output per sector is linked to household consumption in terms of consumption expenditure categories using a production-consumption conversion matrix (Cazcarro et al., 2020). The electricity sector is divided into two power generation technologies – conventional electricity and electricity from renewables –according to technology-specific production shares provided by Eurostat (2017).

Cross-price substitution elasticities in production (other than fossil fuel industries) are based on empirical estimates by Koesler and Schymura (2015). The elasticities of substitution in fossil fuel production sectors are calibrated to match exogenous estimates of fossil fuel supply elasticities (Graham et al., 1999; Krichene, 2002; Ringlund et al., 2008).

The MS model builds on data from the Spanish Household Budget Survey (SHBS) for 2014 (INE, 2018a), which corresponds to the base year for the Spanish input-output table used to parametrize the CGE model. The SHBS is a representative cross-sectional survey of the Spanish population that collects annual information on consumption patterns as well as socio-economic characteristics. It includes approximately 22,000 households. The econometric estimation of the AIDS model is based on cross-sectional data for survey waves from 2006 through 2013, resulting in a data sample of almost 170,000 households (see Appendix A.2). The main limitation of using several waves of cross-sectional data is that it does not allow for observing transitional effects. One solution to solve this limitation could be to construct a so-called pseudo-panel using household cohorts (see e.g. Deaton, 1985), but due to the extensive data requirements to construct a pseudo-panel and the limitations of such an approach, the estimation of our AIDS model is based on repeated cross-sectional waves as a widespread approach in empirical analysis.[5] Moreover, our economic impact assessment builds on comparative statics and does not investigate transitional effects in a dynamic setting, so the advantage of using pseudo-panels is limited in our context (see Appendix A.1 for a more in-depth discussion).

Harmonization of input–output data and microsimulation data requires that we scale the total expenditures of households in the microsimulation data to match total household expenditures in the input-output table. Similarly, on the income side, we need to scale capital and labor income in the microsimulation data to match total income in the input-output table. Given the lack of information on savings in the SHBS, we distribute total savings across households in proportion to their capital income. The residual between factor income and savings is filled by government transfers.[6]

Table 1 summarizes the sectors and commodities explicitly represented in the combined dataset for our CGE-MS simulation analysis.

4. Policy scenarios and simulation results

4.1. Policy scenarios

Our research interest is to assess the household incidence of different

[5] The use of cross-sectional waves from household expenditure surveys to estimate demand systems is widely applied in the energy economics literature. See, e.g.: Nicol (2003) for the USA and Canada, Okonkwo (2020) for South Africa; Pashardes et al. (2014) for Cyprus; Rosas-Flores et al. (2017) for Mexico; or Tovar-Reaños and Wölfing (2018) for Germany.

[6] Appendix A.2. describes in more detail the harmonization of microdata with national input-output.

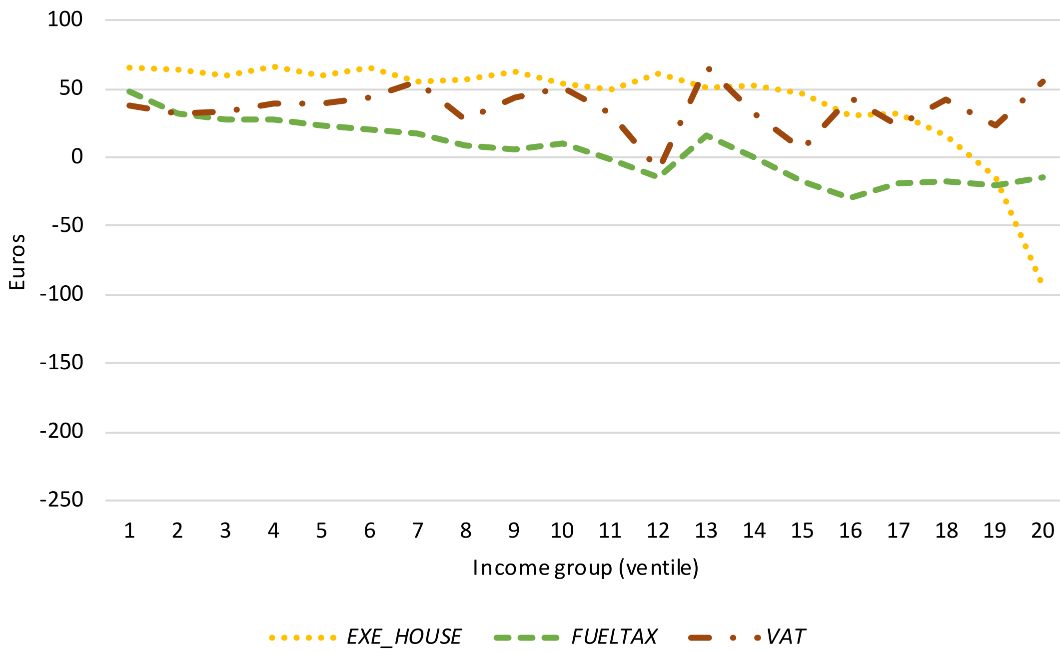

Fig. 4. Real income change by income group (Euros from BaU).

schemes for financing the promotion of RES-E in Spain. The benchmark for comparison is the business-as-usual (*BaU*) situation for our base year 2014, in which renewable electricity generation is subsidized by means of an economy-wide electricity surcharge paid by all consumers (industries and households). In our counterfactual policy scenarios, we examine three alternative options for financing RES-E promotion: (i) exempting residential consumers from the electricity surcharge so that the surcharge is borne only by industrial consumers (scenario *EXE_HOUSE*), (ii) increasing mineral oil taxes (scenario *FUELTAX*), and (iii) increasing value-added taxes (scenario *VAT*). The latter two scenarios reflect policy proposals by various Spanish institutions (CEOE, 2014) and international organizations (IEA, 2015, OECD, 2018). In all policy counterfactuals for alternative subsidy payment schemes, we keep the total electricity generation from renewable energy sources at the *BaU* level to ensure a coherent cost-effectiveness analysis. Table 2 summarizes the three different financing options (with their acronyms) that we consider as alternatives to the *BaU* policy regime.

In our presentation of the simulation results, we report the household incidence of policy regulation as the percentage change in Hicksian equivalent variation (HEV) in income.[7]

4.2. Incidence by income group

Fig. 3 shows the incidence of the three alternative RES-E financing options across income ventiles with group 1 representing the lowest income ventile and group 20 representing the highest income ventile. Fig. 4 converts the percentage income effects across households into monetary units.

The regressive impacts of RES-E promotion[8] are mitigated for all three options – most significantly by exempting households from the electricity surcharge (*EXE HOUSE*), followed by higher mineral oil taxation *(FUELTAX)* and value-added taxation (*VAT*).

The combined CGE-MS framework allows us to investigate the drivers of the policy incidence in more detail, as it captures both the expenditure as well as the income channel at the disaggregated household level. For homothetic preferences, household utility u equals income m divided by the price of utility p.[9] The aggregate impact of a policy shock on utility (welfare) can then be decomposed into expenditure and income effects:

$$\frac{du}{u}=\frac{d(m/p)}{m/p}=\frac{\frac{m+dm}{p+dp}-\frac{m}{p}}{m/p}=\frac{\frac{m}{p+dp}-\frac{m}{p}}{m/p}+\frac{\frac{dm}{p+dp}}{m/p}=\underbrace{\left(\frac{1}{1+\widehat{p}}-1\right)}_{\text{Expenditure effect}}+\underbrace{\frac{\widehat{m}}{1+\widehat{p}}}_{\text{Income effect}} \tag{1}$$

where relative changes in any variable υ are denoted by: $\widehat{\upsilon}=\frac{d\upsilon}{\upsilon}$.

Fig. 5 decomposes the composite welfare change into its income and expenditure components. For compactness, we focus on income quintiles. We see that in scenario *EXE HOUSE* – in which households are exempted from paying the electricity surcharge – the welfare effects through the expenditure channel are positive, while the welfare effects through the income channel are negative. The positive welfare effects on the expenditure side dominate the negative welfare effects on the income side. The expenditure-side welfare gains are most pronounced for the poorer households, reflecting the importance of electricity consumption in the expenditure patterns for low-income groups. The share of disposable income spent on electricity is around 5% in the lowest income group (first ventile), while it is just around 1% in the highest income group (twentieth ventile). Thus, exempting households from paying the electricity surcharge is particularly beneficial on the expenditure side for low-income households. For scenarios *FUELTAX* and *VAT*, the overall change in incidence compared to *BaU* is also progressive, but now all households have a positive welfare impact through the income channel, indicating an increase in the overall economic efficiency of resource allocation. On the expenditure side, only poorer households benefit in scenario *FUELTAX*, while all households experience negative welfare effects through the expenditure channel if the economy-wide electricity surcharge is replaced by an increase in value-added taxes (scenario *VAT*).

[7] The Hicksian equivalent variation in income denotes the amount that must be added to (or subtracted from) the *BaU* income of the household so that it enjoys a utility level equal to that in the counterfactual policy scenario on the basis of ex-ante (*BaU*) relative prices.

[8] To verify the regressive impacts of the current RES-E promotion we have compared the *BaU* to a hypothetical scenario where electricity surcharges are abolished (see Figure B.1 in Appendix B).

[9] Utility (welfare) in our analysis refers to real consumption, and therefore the price of utility is equal to the consumption price index.

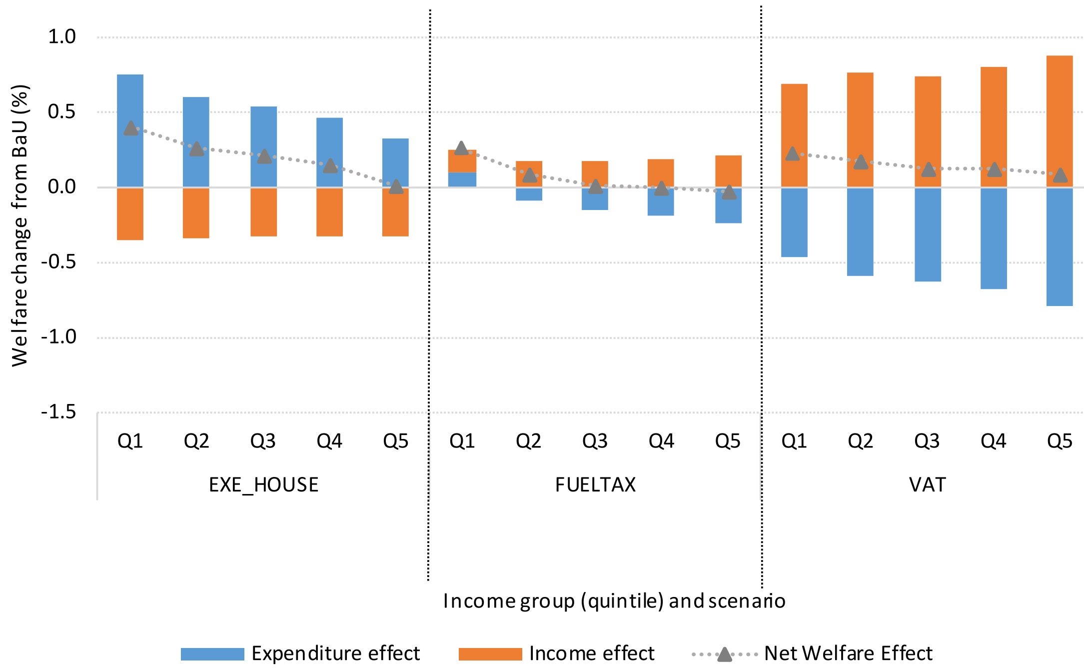

Fig. 5. Expenditure, income, and net welfare effects by income group (% HEV in income).

The expenditure and income welfare effects are determined by changes in consumption and factor prices. Table 3 reports the changes in (energy) consumption prices and factor prices in the three alternative RES-E financing options. Table 4 reports the changes in household-specific price indices, with prices weighted by the income sources and consumption pattern of the different households.

Across all scenarios, electricity prices for residential consumer decline as they no longer pay a surcharge, which in itself leads to a progressive expenditure welfare effect. In scenario *FUELTAX*, the lower electricity prices are counteracted by higher prices for other energy consumption goods such as fuel, resulting in a negative total expenditure effect for all income groups, except the poorest quintile, for whom expenditures on fuel and particularly on transport figure are less significant. In scenario *VAT*, the expenditure-side welfare effects are consistently negative and become more pronounced for richer households, again reflecting the more important role of electricity relative to other consumption goods in the expenditure patterns of low-income groups.

On the income-side, scenario *EXE_HOUSE* involves negative income effects for labor, capital, and transfers, while scenario *FUELTAX* leads to income losses except for capital, and scenario *VAT* induces positive income effects for capital and labor, and a negative income effect for transfers. Since scenario *VAT* is the broadest financing scenario, it reduces factor productivity the least, as evidenced by positive effects on capital and labor prices compared to *BaU*. In terms of income composition, capital income is fairly equally distributed in Spain if we attribute imputed rents to capital earnings, while labor income is more important for middle- and high-income groups. The main difference in the income composition arises from transfer payments, which are progressive. A reduction in transfer payments leads to welfare gains for the richest and welfare losses for the poorest households. The welfare decomposition shows that the net distributional effects across the different financing schemes are dominated by the progressive expenditure effects (mainly due to the importance of electricity consumption for low-income groups).

4.3. Inequality analysis

The rich representation of household heterogeneity in our dataset allows us to explore the implications of alternative financing options on economic inequality as an important policy criterion. For our inequality analysis we use common measures of inequality listed in Table 5.

Table 6 shows the results for each inequality measure for the three alternative RES-E financing options. We find that while there is no unambiguous ranking of the inequality measures, scenarios *FUELTAX* and *EXE-HOUSE* perform significantly better than the *BaU* regulation in reducing inequality. Our results therefore urge caution against the use of economy-wide electricity surcharges when policymakers are concerned about inequality.

4.4. Impacts on vulnerable groups

Public concerns on the incidence of RES-E promotion are often directed to households at risk of energy poverty. For this reason, the Spanish government has introduced a discount scheme called the 'bono social' (social bonus) which reduces the electricity bills of vulnerable consumers.[10] We adopt the classification criteria used in that scheme and find that 2.8 million households (14% of all households) are eligible for the bonus, while we classify the other households as non-vulnerable. Fig. 6 shows the decomposition of welfare changes for these two household types.

As expected, vulnerable households which stand out for relatively high electricity expenditure shares and belong to the low-income classes[11] are more likely to benefit from RES-E financing schemes that lower electricity consumption prices. The share of electricity expenditures in disposable income is about 5% for vulnerable households, while it is only about 2% for non-vulnerable households. On the income side, the differences in the transfer shares between vulnerable and non-vulnerable households are the main driver for different impacts of scenarios *EXE_HOUSE* and *VAT*.

Using information on non-income socio-economic household characteristics, Fig. 7 shows the welfare effects of alternative RES-E financing schemes for four different household types: (i) couples with

[10] See: http://www.bonosocial.gob.es/#inicio

[11] Most of the criteria for achieving the social bonus relate to household income. Therefore, the bulk of the identified vulnerable households belongs to low-income groups. Only in the case of large families, did we identify some vulnerable households belonging to middle- and high-income groups.

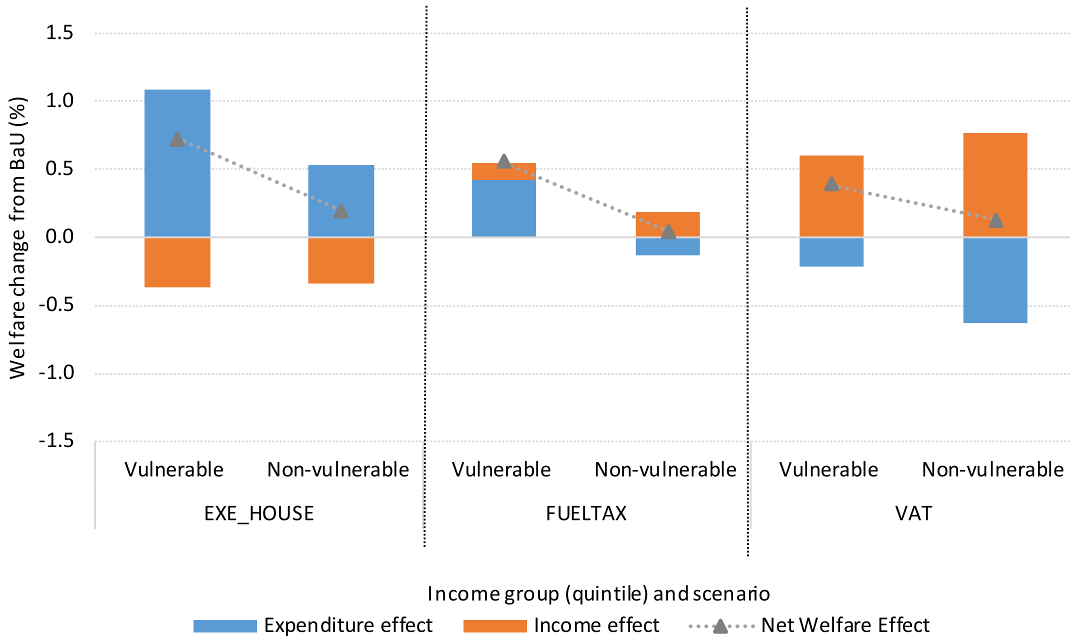

Fig. 6. Expenditure, income and net welfare effects by (non-)vulnerable household (% HEV in income).

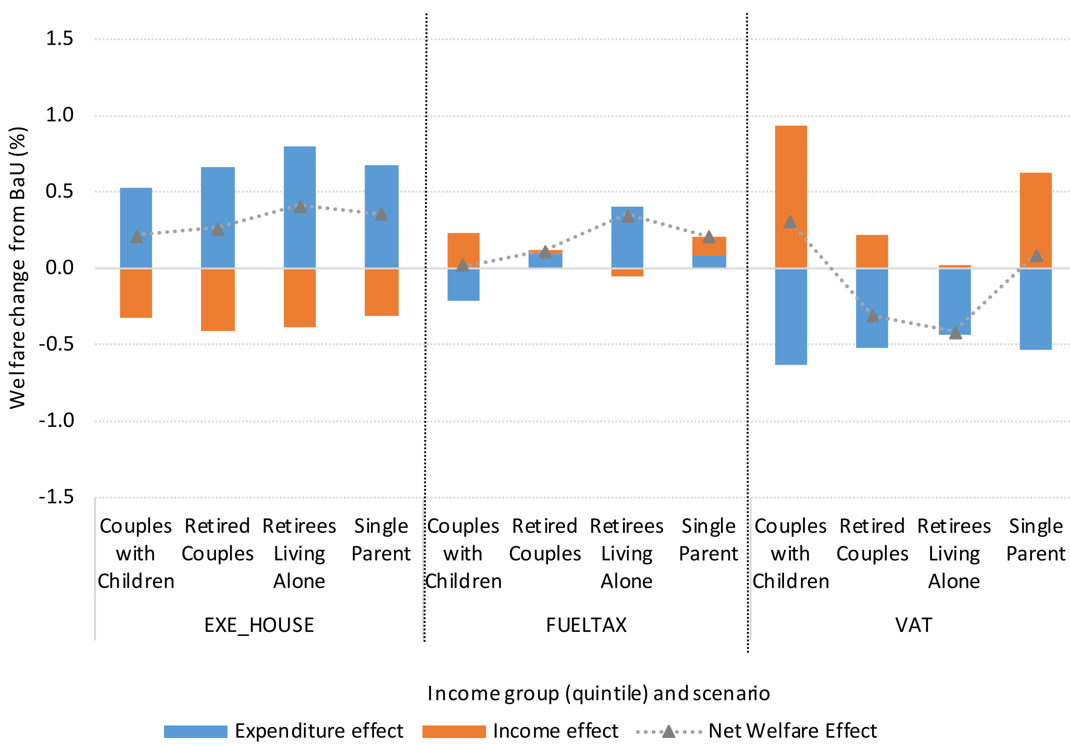

Fig. 7. Expenditure, income, and net welfare effects by household type (% HEV in income).

children, (ii) retired couples, (iii) retirees living alone, and (iv) single-parent households.

Fig. 7 indicates that exempting households from the electricity surcharge (*EXE_HOUSE*) is beneficial for all four household types, although to quite different degrees. The pattern of net incidence is similar for scenarios *EXE_HOUSE* and *FUELTAX*. Those who benefit most from *EXE_HOUSE* or *FUELTAX* are households consisting of retirees living alone who have relatively large electricity expenditure shares. Scenario *VAT*, in turn, leads to welfare losses for retired households, since the negative expenditure effect is not compensated by the income effect. Given that households with retirees constitute a significant share of the population (28% of the total household population), the incidence of policy reforms for this group is of high relevance.

4.5. *Impacts on other household categories*

Figs. 8–10 show expenditure, income, and net welfare effects across household for our three alternative RES-E financing schemes by the following socio-economic categories: Educational level of the main breadwinner (BW), age of the BW, gender of the BW, country of origin of the BW, rural dimension of the household, and families with children. Since each of these categories includes subgroups, the figures present

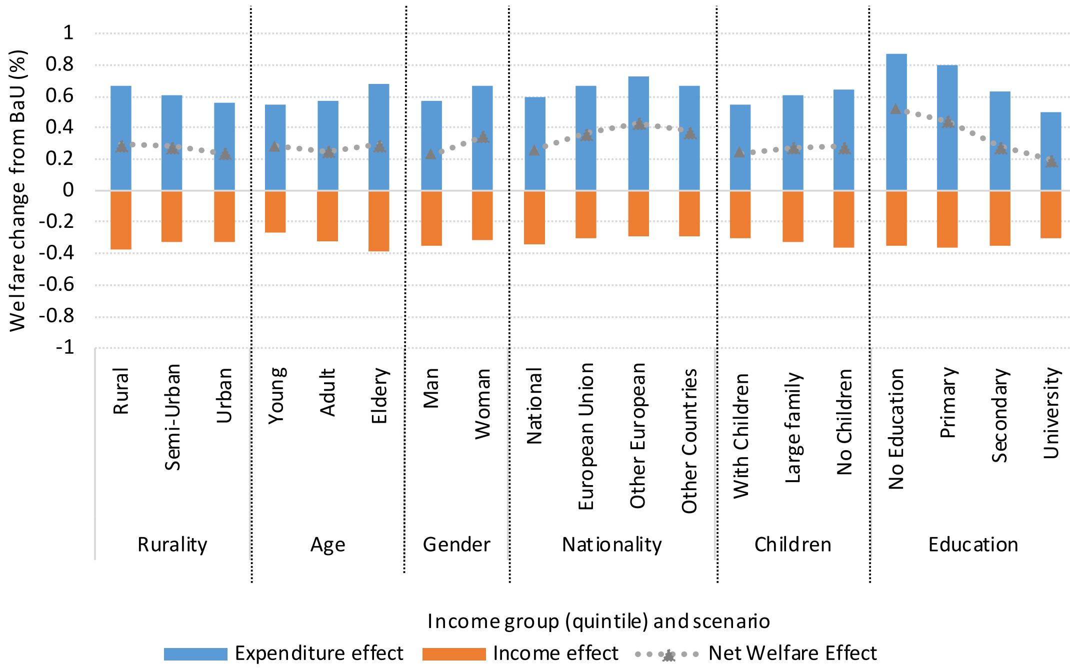

Fig. 8. Expenditure, income, and net welfare effects by other household categories under scenario EXE_HOUSE (% HEV in income).

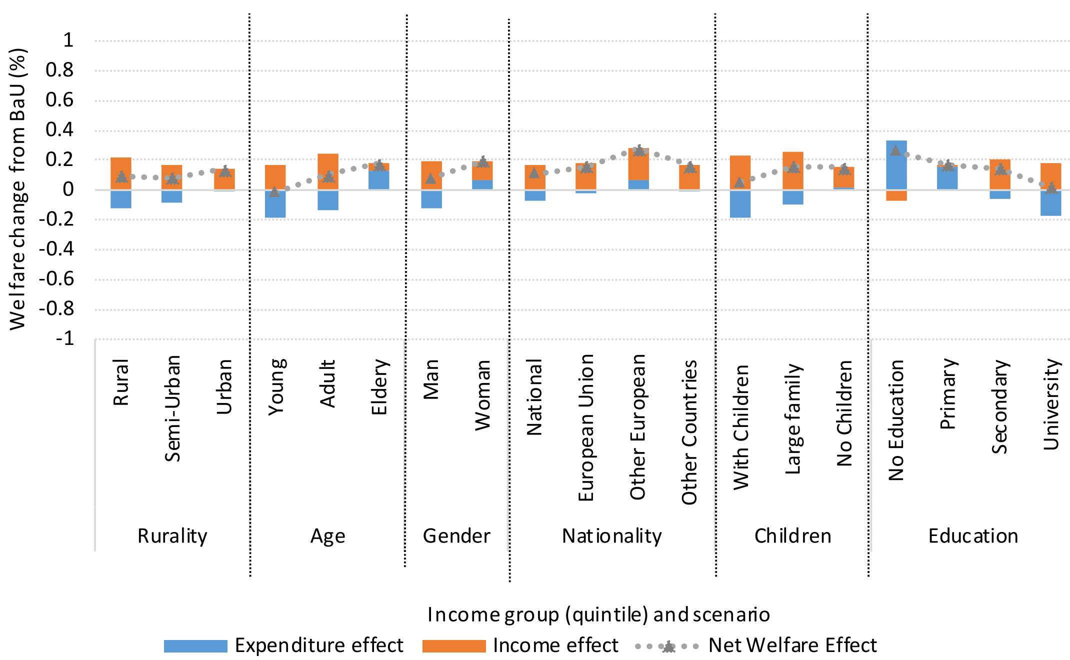

Fig. 9. Expenditure, income, and net welfare effects by other household categories under scenario FUELTAX (% HEV in income).

impacts by subgroup, with the relevant category mentioned in parentheses.[12]

[12] The categories feature the following subgroups of households. Educational level: No Education; Primary; Secondary; University. Rurality: Rural; Semi-urban; Urban. Breadwinner's age: Under 35 years old (Young); Between 35 and 65 years old (Adult); Over 65 years old (Elderly). Breadwinner's gender: Man; Woman. Origin of the main breadwinner: Born in Spain (National); Born in a country of the European Union (European Union); Born in another European country other than the EU (Other European); Born outside of Europe (Other Countries). Families with children (Children): No Children; With one or two children (With Children); Large family.

Fig. 8 indicates that exempting households from the electricity surcharge (*EXE_HOUSE*) is particularly beneficial for households whose breadwinner has no education or just primary education. These categories of households are related to elderly households (81% of households whose breadwinner has no education are over 65 years old, while among households with primary education 73% are over 65 years old), whose higher electricity expenditure explains why they are better off when households are exempt from the electricity surcharge (as we also showed in Section 4.4). Moreover, since these households spend a smaller share of their income on private transportation, they are the ones that obtain the largest welfare gains under scenario *FUELTAX* (Fig. 9), despite the increase in fuel prices. However, scenario *VAT* leads

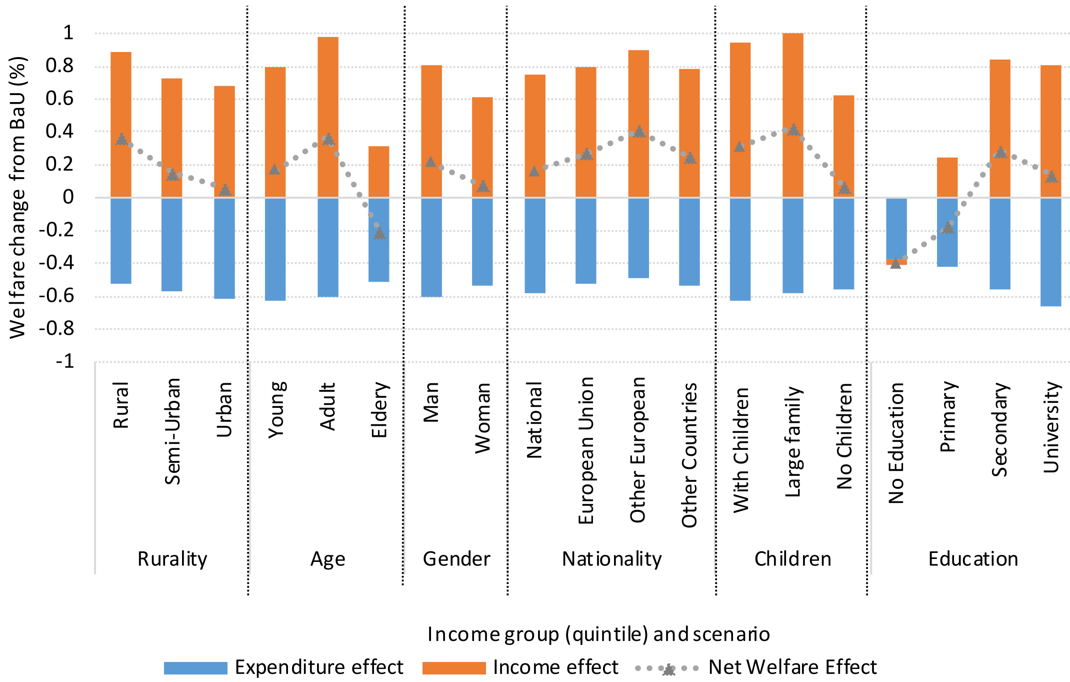

Fig. 10. Expenditure, income, and net welfare effects by other household categories under scenario VAT (% HEV in income).

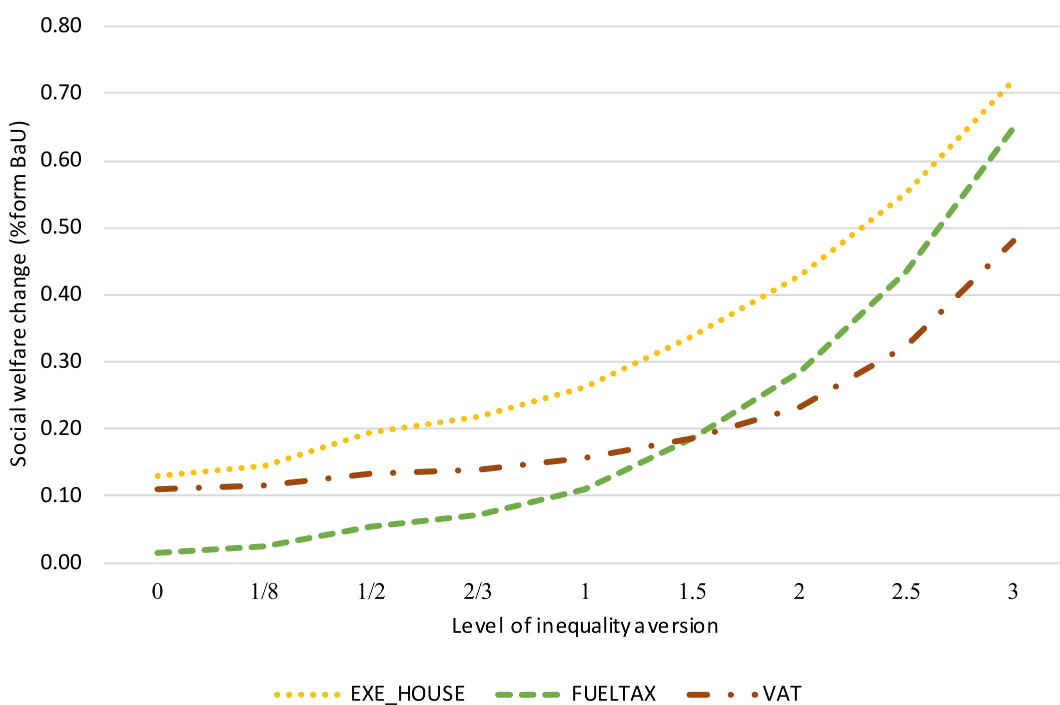

Fig. 11. Social welfare (% HEV in income).

to net welfare losses for these households, as the welfare gains from income do not offset the losses from the expenditure channel.

Households consisting of families with children, or those whose breadwinner has a university degree, is a young person or an adult, benefit the least both when they are exempt from the electricity surcharge (scenario *EXE_HOUSE*) and in the case where RES-E promotion is financed through higher fuel taxes (scenario *FUELTAX*). Families with children and those whose breadwinner has higher education or is an adult are among the highest income groups and therefore suffer from the progressive impacts of the *EXE_HOUSE* and *FUELTAX* financing options (see Section 4.2). However, for these wealthier households, factor earnings (capital and labor) are the main source of income, so gains in labor and capital earnings offset the expenditure welfare losses in the *VAT* scenario (Fig. 10), leading to positive net welfare effects. In the case of young people, although they are not in the highest income groups, they tend to spend a smaller share of their income on electricity while spending more on fuel and transportation, which explains their incidence for scenarios *EXE_HOUSE* or *FUELTAX*.

Finally, there are two household dimensions that deserve separate mention: Gender and rurality. In terms of gender, Figs. 8 and 9 show that

Spanish households whose breadwinner is a woman tend to spend a higher proportion of their income to electricity than those whose breadwinner is a man. This explains why female-headed households benefit more from the *EXE_HOUSE* or *FUELTAX* financing options. Households where women are the main breadwinner tend to suffer more energy poverty in Spain (Clancy et al., 2017), so policies that ease electricity bills could also reduce this problem. Another relevant dimension is rurality. Households living in rural areas tend to suffer more from environmental policies because they are more dependent on energy (Labandeira et al., 2004 or Romero-Jordan et al., 2014), especially in terms of fuel for private transportation, when public transport is difficult to access. Our results show that these households can benefit from the elimination of the electricity surcharge (Fig. 8) and even that the savings in electricity expenditures can almost offset the increase in fuel prices when RES-E is financed through higher fuel taxes, resulting in a welfare effect close to zero for rural households (Fig. 9). Scenario *VAT*, in turn, generates welfare gains for rural households, as increased labor and capital earnings compensate the negative expenditure impact (Fig. 10).

4.6. Social welfare analysis

So far, we have quantified the incidence of RES-E promotion among heterogeneous households without investigating potential trade-offs between efficiency and equity. We can assess such trade-offs using the wide-spread social welfare function (SWF) proposed by Atkinson (1970):

$$\mathrm{SWF} = \frac{1}{N}\sum_{h}\frac{Y_h^{1-\varepsilon}}{1-\varepsilon} \tag{2}$$

where Y_h represents the real income level by household h, ε is the inequality-aversion coefficient, and N denotes the population. Following Böhringer et al. (2012), we present welfare changes as changes in the equally distributed equivalent income (Y_{ede}):

$$\mathrm{Y}_{ede} = \left[\frac{1}{N}\sum_{h} Y_h^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}, \, if \ \varepsilon \neq 1 \tag{3}$$

$$\mathrm{Y}_{ede} = \prod_{h} Y_h^{\frac{1}{N}}, \, if \ \varepsilon = 1 \tag{4}$$

Trade-offs between efficiency and equity in alternative RES-E promotion scenarios can be summarized by alternative choices for the inequality-aversion coefficient ε. A zero value of ε corresponds to social preferences in which cost distribution among households is irrelevant. This amounts to a utilitarian focus on gross efficiency, since money-metric utility is perfectly substitutable between households. As ε increases, society becomes more concerned on the well-being of poorer households relative to richer households. Fig. 11 shows the impacts on social welfare under the three financing scenarios for alternative degrees of inequality aversion ranging from "0" to "3".[13]

The results confirm our initial findings on the regressivity of the *BaU* regulation, which relies on an economy-wide electricity surcharge to finance RES-E subsidies. The three alternative financing options are superior from an overall social welfare perspective when equity considerations come into play. The higher the inequality aversion, the better off society is under each alternative option, reflecting its progressive effects. Since exempting households from the surcharge has the strongest positive welfare effect for low-income households, scenario *EXE_HOUSE* stands out for the largest social welfare gains.

4.7. Impacts on energy-intensive and trade-exposed industries

RES-E promotion that results in higher energy prices can have adverse impacts not only for households that spend a larger share of their income on energy, but also for energy-intensive and trade-exposed (EITE) industries. To the extent that these industries cannot pass on additional cost of policy reforms through higher prices, they will face negative effects on output. To gain insights into potential trade-offs between competitiveness and equity considerations, we run a sensitivity analysis for alternative degrees of trade openness. Trade openness can be easily parametrized in our CGE model by alternative values for Armington trade elasticities. The higher the Armington elasticity, the better imported varieties substitute for domestically produced varieties. The central case parameterization underlying our core simulation results is labeled *ref*, while the labels *half* and *double* refer to halving or doubling the value of the elasticities, respectively.

The results of our sensitivity analysis are shown in Table 7. For scenarios *EXE_HOUSE* and *FUELTAX,* EITE industries face higher input cost compared to *BaU* which is reflected in a decrease of EITE output compared to *BaU*. The EITE sectors are quite fuel-intensive, which explains that they perform worst in terms of output for scenario *FUELTAX*. Under scenario *VAT*, the EITE sectors face a slightly lower cost burden than under the economy-wide electricity surcharge – hence the output increases compared to *BaU*. Our results show that there may be a trade-off between EITE competitiveness (measured in terms of EITE output impacts) and equity concerns – for example, the lowest income quintile prefers scenario *EXE-HOUSE* to scenario *VAT* while EITE industries would have the opposite ranking in terms of output. At the same time, we find that policy reforms favouring EITE output may come at the expense of aggregate output in other (Non-EITE) sectors.

As we increase the trade responsiveness of EITE industries, policy-induced changes in the cost burden of financing RES-E amplify the output effects. While alternative degrees of trade openness matter for the sectoral output implications, differences in welfare impacts across households tend to be negligible, suggesting that the overall contribution of EITE industries in gross value-added is relatively small. All qualitative findings on the household incidence of alternative RES-E promotion schemes remain robust.

5. Conclusions

In the fight against climate change, the promotion of electricity from renewable energy sources – so-called RES-E – has become a policy priority for governments around the world. At the same time, there are concerns that RES-E promotion can drive up electricity prices, creating an economic burden, especially for low-income households. A prime example is Spain, where long-term subsidy schemes for RES-E until 2017 led to a massive expansion of RES-E along with significant electricity surcharges for industry and households. In this paper we apply a computable general equilibrium model together with a microsimulation model to quantify the distributional impacts of three alternative financing schemes for RES-E subsidies in Spain. The first option exempts households from the RES-E electricity surcharge, so that it is paid only by the industry. The other two options replace the electricity surcharge with either an increase in mineral oil taxes or an increase in value-added taxes.

Our simulation results show that the adverse impacts of RES-E promotion on low- income households can be mitigated either by exempting households from the surcharge or by replacing the surcharge with an increase in mineral oil taxes or value-added taxes. All three financing alternatives have a progressive effect by lowering electricity prices, which particularly benefits low-income households that spend a higher share of their income on electricity. From an economy-wide perspective there is hardly an efficiency-equity trade-off to start with – when equity concerns gain in weight all three alternative financing options are clearly preferable to an economy-wide electricity surcharge.

[13] Creedy and Sleeman (2006) use ε = 0.2 and ε = 1.2. The survey by Pirttilä and Uusitalo (2010) suggests an upper bound of 3.

Furthermore, our results indicate potential competitiveness losses for energy-intensive and trade-exposed industries if policy reforms impose higher energy cost on them.

In summary, our analysis of the Spanish RES-E policy warrants caution against the use of economy-wide electricity surcharges to finance RES-E promotion, from both equity and efficiency perspectives.

Acknowledgements

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Appendix A. Estimation of household demand system

A.1. AIDS model

We use the flexible almost ideal demand system (AIDS) proposed by Deaton and Muellbauer (1980) to estimate household demand responses based on empirical data. The AIDS model satisfies fundamental axioms of economic consumption theory.

The log-linear approximation (LAIDS) of demand functions is as follows:

$$w_i = \alpha_i + \sum_{j=1}^{n} \gamma_{ij} ln\, p_j + \beta_i ln\left(Y/_{\widetilde{p}} \right) + t + d + e_i, \tag{A.1}$$

where w_i represents the budget share associated with good i for a particular household, α_i is a constant, γ_{ij} is the slope coefficient associated with the j-th good in the i-th share equation, p_j is the price of good j, β_i is the slope coefficient for real income, $\widetilde{p}$ stands for the geometric Stone price index,[14] and Y denotes household income (hence, $Y/\widetilde{p}$ represents real income). The time trend variable is denoted with t. Furthermore, d is a set of dummy variables that – in the case of our household dataset (see Section A.2) – control (i) the type of household,[15] (ii) the region where the household is located in terms of the seven regions (NUTS 1),[16] (iii) whether the household has heating, (iv) the number of rooms in the household, (v) the age of the breadwinner, (vi) whether the breadwinner is retired, (vii) the number of members, (viii) whether the household lives in a regional capital, (ix) the level of rurality, (x) whether the household lives in property and (xi) the gender of the breadwinner. Finally, e_i denotes the error term. The adding-up and homogeneity restrictions of Eq. (A.1) are as follows:

$$\sum_{i=1}^{n} \alpha_i = 1, \tag{A.2}$$

$$\sum_{j=1}^{n} \gamma_{ij} = 0, \tag{A.3}$$

$$\sum_{i=1}^{n} \beta_i = 0, \tag{A.4}$$

and the symmetry condition is given by:

$$\gamma_{ij} = \gamma_{ji}, \tag{A.5}$$

Finally, the sum of w_i must satisfy:

$$\sum_{i=1}^{n} w_i = 1 \tag{A.6}$$

Given that the AIDS is made up of a system of dependent linear equations, we estimate n-1 equations of the system. The parameter values of the omitted equation can then be readily derived from Eqs. (A.2) to (A.6). In the estimation of Eq. (A.1), household expenditure is used as a proxy of income, firstly because income is strongly under-reported in household panel surveys (see for example Wadud et al., 2009), and secondly because household expenditure is a good proxy for permanent income (Poterba, 1990 or INE, 2006).

We apply the estimator of Seemingly Unrelated Regression Equations (Zellner, 1962) in the system of demand Eqs. (A.1) for 9 composite consumption categories: *Food & Beverage*, *Housing*, *Fuel*, *Electricity*, *Heating*, *Public Transport*, *Education & Leisure*, *Durables*, and *Other Goods & Services*. The matrix of own-price, cross-price, and expenditure (income) elasticities is calculated according to:

[14] The Stone price index is defined as follows: $log\widetilde{p} = \sum_{i=1}^{n} w_i ln\, p_i$.

[15] The household categories used in our estimation are the following: (i) adults alone, (ii) couple without children, (iii) couple with children, (iv) single-parent households, and (v) the composite of other households.

[16] According to the Nomenclature of Territorial Units for Statistics at the first level (NUTS 1) there are seven regions in Spain: (i) North West (Galicia, Asturias, Cantabria), (ii) North East (Basque Community, Navarre, La Rioja, Aragon), (iii) Community of Madrid (Community of Madrid), (iv) Centre (Castile and León, Castile-La Mancha, Extremadura), (v) East (Catalonia, Valencian Community, Balearic Islands), (vi) South (Andalusia, Region of Murcia, Ceuta, Melilla), and (vii) Canary Islands.

$$\text{Marshallian own} - \text{price elasticity} : \varepsilon_{ii} = \frac{\gamma_{ii}}{w_i} - 1 \quad \text{(A.7)}$$

$$\text{Marshallian cross} - \text{price elasticity} : \varepsilon_{ij} = \frac{\gamma_{ij}}{w_i} \quad \text{(A.8)}$$

$$\text{Expenditure elasticity} : \theta_i = \frac{\beta_i}{w_i} + 1 \quad \text{(A.9)}$$

The price and expenditure elasticities obtained are listed in Table A.1. The final column reports the real expenditure elasticities. The main diagonal of the matrix shows the own-price elasticities while the remaining elements are cross-price elasticities. As expected, the sign of own-price elasticities is negative. The expenditure elasticity is positive for all commodities (classifying them as normal goods).

A.2. Data

The data source with information on different households is the Spanish Household Budget Survey (SHBS). The SHBS provides a representative cross-sectional survey of the entire Spanish population with annual information on consumption patterns and socioeconomic characteristics for around 22,000 Spanish households. Our econometric estimation of the LAIDS model is based on cross-sectional data for survey waves from 2006 through 2013, resulting in a data sample of almost 170,000 households.

The SHBS microdata for heterogeneous households must be aligned with the aggregate national data accounts on expenditure and income for the representative household in the Spanish input-output table. Since SHBS does not include data on income sources, we need to use complementary information from the Statistics on Income and Living Conditions survey (SLIC, INE, 2018c) to derive household income from labor, capital, and transfers. Following Rutherford and Tarr (2008), we run a logit regression of labor and capital income shares on SLIC using common socio-characteristics of households to derive factor income shares for the SHBS households. Transfers are then obtained as a residual. Table A.2 shows the income shares by quintile from the SILC regression and the derived shares for SLIC.

Table A.1
Own-, cross-price and expenditure elasticities.

	Food & Beverages	Housing	Fuel	Electricity	Heating	Public Transport	Education & Leisure	Durables	Other Goods & Services	Real Expenditure
Food & Beverages	−0.24	−0.10	0.05	0.00	−0.04	−0.17	−0.37	0.39	−0.51	0.97
Housing	−0.06	−0.33	−0.06	0.03	0.07	0.05	−0.18	−0.40	−0.12	0.98
Fuel	0.15	−0.26	−0.58	0.22	0.09	−0.10	−0.75	0.13	0.08	1.35
Electricity	−0.01	0.34	0.49	−0.02	−0.66	−0.15	1.13	−0.35	−1.77	0.63
Heating	−0.24	0.67	0.21	−0.65	−0.89	0.40	1.54	−1.58	−0.44	0.63
Public Transport	−0.78	0.39	−0.16	−0.11	0.29	−0.56	−0.81	0.25	0.50	0.88
Education & Leisure	−0.48	−0.38	−0.35	0.24	0.32	−0.23	−2.84	1.04	1.69	0.98
Durables	0.60	−1.00	0.07	−0.09	−0.39	0.08	1.23	−0.12	−1.38	1.19
Other Goods & Services	−0.51	−0.20	0.03	−0.29	−0.07	0.11	1.31	−0.91	−0.47	0.97

Table A.2
Factor income shares by income quintile.

	Labor		Capital		Transfers	
Income group	SLIC	SHBS (derived)	SLIC	SHBS (derived)	SLIC	SHBS (derived)
Q1	0.26	0.22	0.15	0.14	0.59	0.64
Q2	0.41	0.43	0.13	0.12	0.46	0.45
Q3	0.56	0.53	0.13	0.13	0.31	0.34
Q4	0.68	0.65	0.13	0.14	0.19	0.21
Q5	0.86	0.81	0.17	0.17	−0.03	0.02

Table 1
Model sectors and commodities.

Sectors	Commodities
Agriculture	Food & Beverages
Mining	Housing
Coal	Fuel
Crude oil and gas	Electricity
Petroleum products	Heating
Power electricity sector	Public Transport
Gas and distribution	Education & Leisure
Manufacturing	Durables
Energy intensity	Other Goods & Services
Services	
Transport	

Table 2
Overview of policy scenarios.

Scenario acronym	Financing of RES-E subsidies
EXE_HOUSE	Electricity surcharge (exempting households)
FUELTAX	Mineral oil tax on households and industries
VAT	Value-added tax

Table 3
Energy consumption prices and factor prices.

	EXE_HOUSE	*FUELTAX*	*VAT*
Nominal Factor prices price (in % from *BaU*)			
Capital	−0.25	0.21	0.65
Labor	−0.23	−0.02	0.20
Transfers	−0.34	−0.20	−0.42
Energy consumption prices (in % from *BaU*)			
Electricity	−21.18	−14.50	−14.99
Fuel	0.12	7.90	1.04
Heating	6.74	8.03	5.33
Transport	0.07	0.68	1.08

Table 4
Income and consumption price indices.

	EXE_HOUSE	*FUELTAX*	*VAT*
Income price index by income group (quintile) (% from *BaU*)			
Q1	−0.34	0.16	0.71
Q2	−0.33	0.18	0.77
Q3	−0.32	0.17	0.75
Q4	−0.32	0.19	0.81
Q5	−0.32	0.21	0.89
Consumption price index by income group (quintile) (% from *BaU*)			
Q1	−0.75	−0.09	0.47
Q2	−0.59	0.09	0.59
Q3	−0.54	0.16	0.63
Q4	−0.47	0.20	0.69
Q5	−0.33	0.24	0.79

Table 5
Inequality measures.

Top 1%	The share of all income received by the Top 1% households with highest disposable income.
Top 10%	The share of all income received by the Top 10% households with highest disposable income.
Ratio 80/20	The share of all income received by the top 20% of households (top quintile) compared to the bottom 20% of households (bottom quintile).
Palma Ratio	The share of all income received by the top 10% of households compared to the bottom 40% of households.
Gini Index	Measures the deviation of income distribution across households from a perfectly equal distribution.

Table 6
Inequality effects by inequality measure and alternative RES-E financing option.

	BaU	*EXE_HOUSE*	*FUELTAX*	*VAT*
Top 1%	4.27%	4.26%	4.24%	4.22%
Top 10%	27.26%	27.19%	27.25%	27.31%
Ratio 80/20	8.216	8.168	8.186	8.202
Palma Ratio	1.739	1.726	1.736	1.745
Gini Index	33.17%	33.03%	33.13%	33.14%

A.3. Limitations of the data used to estimate the AIDS model

The use of cross-sectional data does not allow us to observe changes in consumption patterns of individual households over time (since the households surveyed change over time). Hence, we cannot capture transitional changes in preferences over time for the same households (Burguillo et al., 2019). Tracking changes in individual household behavior over time would require panel data (Hsiao, 2007) – however, such data are not available for Spanish household expenditure. A pragmatic workaround might be to construct a so-called pseudo-panel using cohorts of households

Table 7
Sensitivity analysis on Armington elasticities (% from BaU).

RES-E financing option	*EITE*Armington elasticities*	*Output*		*Welfare*				
		EITE	*Non-EITE*	*Q1*	*Q2*	*Q3*	*Q4*	*Q5*
	ref	−1.63	0.36	0.41	0.26	0.22	0.15	0.01
EXE_HOUSE	*half*	−1.29	0.34	0.41	0.26	0.22	0.15	0.01
	double	−2.19	0.39	0.41	0.26	0.22	0.14	0.01
	ref	−4.85	0.35	0.25	0.09	0.02	0.00	−0.03
FUELTAX	*half*	−4.07	0.29	0.26	0.10	0.02	0.00	−0.02
	double	−6.17	0.43	0.24	0.08	0.01	−0.01	−0.04
	ref	0.40	−0.50	0.22	0.18	0.12	0.12	0.09
VAT	*half*	0.18	−0.49	0.22	0.18	0.12	0.12	0.09
	double	0.74	−0.52	0.22	0.18	0.12	0.12	0.10

* *EITE:* energy-intensive and trade-exposed industries.

(see, e.g., Deaton, 1985). However, the construction of a pseudo-panel data has its own limitations, as discussed, e.g., in Verbeek and Nijman (1992), Verbeek and Vella (2005), McKenzie (2004), or Antman and McKenzie (2007). One of the main drawbacks of pseudo-panels is the presence of potential sampling errors, which arise if the means used to create the pseudo-panel are not representative of the underlying cohort population (Verbeek and Nijman, 1992). These errors can be corrected if the number of individuals grouped in each cohort is sufficiently large. However, there is no consensus on how large the number of individuals per cohort should be (Rumman, 2018), and even if cohort sizes are large, the bias can be still substantial for small samples (Verbeek and Nijman, 1992 or Devereux, 2007). In addition, the use of a large number of individuals per cohort may also imply a decrease in the number of available observations which may reduce the precision of the final estimator (Guillerm, 2017). Therefore, the construction of a pseudo-panel presents a trade-off between the number of individuals per cohort and the number of observations to be estimated.

Due to the extensive data requirements for constructing a pseudo-panel, the estimation of our AIDS model is based on repeated cross-sectional waves as a wide-spread approach in empirical analysis.[17] Note that our economic impact assessment builds on comparative statics and does not investigate transitional effects in a dynamic setting, so the advantage of using pseudo-panels islimited in our context.

A drawback of cross-sectional data is the lack of information on the prices of goods and services consumed by households as a prerequisite for the econometric estimation of our AIDS model. To complement this information, we use the consumer price indices across consumption good categories (ECOICOP – European Classification of Individual Consumption according to Purpose) provided by the Spanish Statistical Office (INE, 2018d). When available in the INE data, we use regionally differentiated consumption prices, as these capture more accurately the real price variations faced by households. Since the ECOICOP categories and the aggregated consumption categories in our AIDS model do not match one-to- one, we construct a composite price index for each consumption category in our AIDS model according to their consumption shares in the ECOICOP categories. Finally, we use the Stone price index to derive the general price index for real income. Fig. A.1. shows the evolution of the price indices used in our estimation for each consumption category.

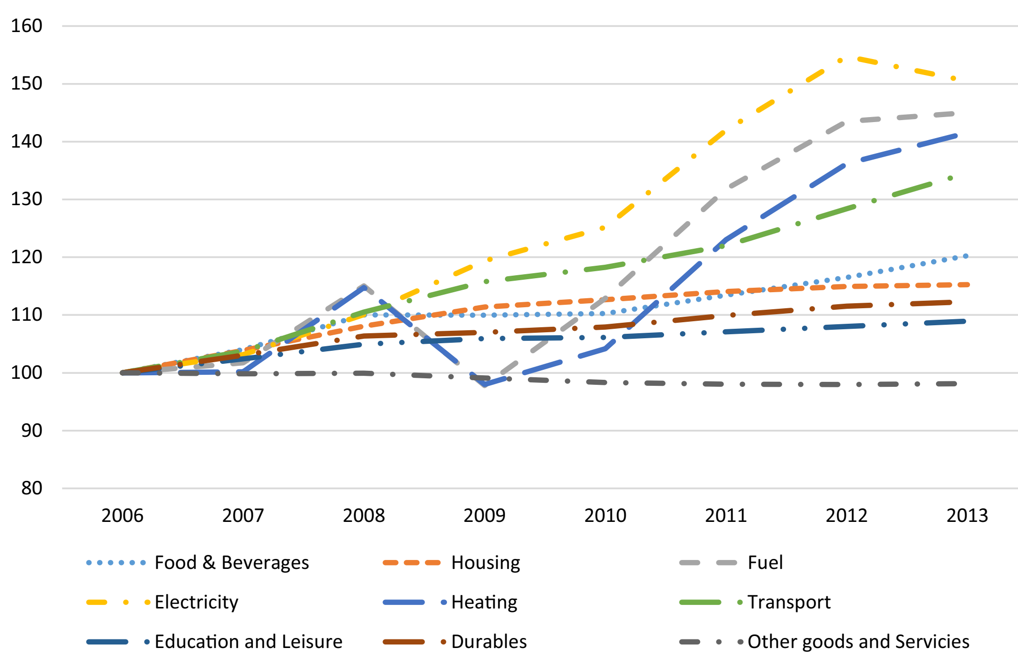

Fig. A.1. Price index evolution by commodity.

[17] The use of cross-sectional waves from household expenditure surveys to estimate demand systems is widely applied in the energy economics literature. See, e.g.: Nicol (2003) for the USA and Canada, Okonkwo (2020) for South Africa; Pashardes et al. (2014) for Cyprus; Rosas-Flores et al. (2017) for Mexico; or Tovar-Reaños and Wölfing (2018) for Germany.

Appendix B. Impacts of RES-E promotion through an electricity surcharge

To show the regressive impacts of the business-as-usual RES-E promotion based on an electricity surcharge, we compare the impacts of *BaU* to a pre-scenario in the absence of RES-E promotion (Fig. B.1). Fig. B.1 confirms the regressivity of *BaU* regulation.

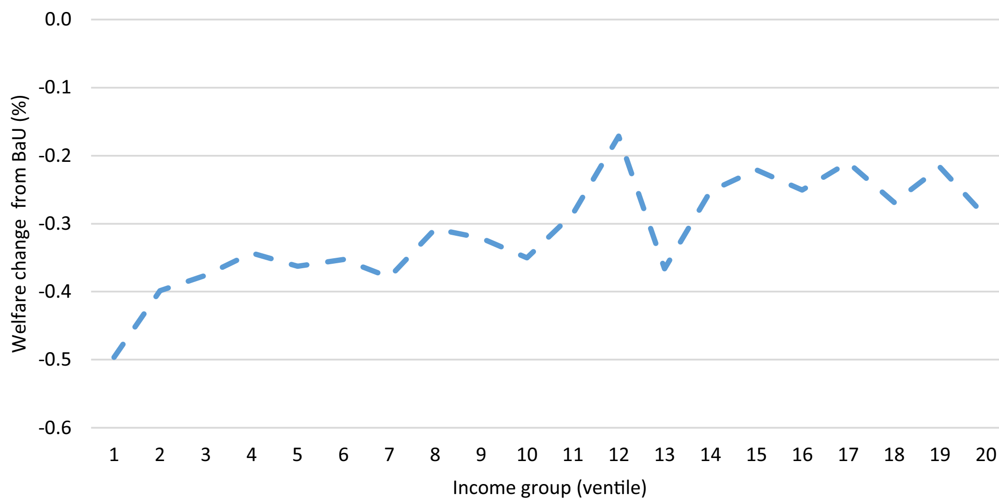

Fig. B.1. Welfare impacts of electricity surcharge abolition (% of HEV in income).

Appendix C. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2021.105705.

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