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Fairness, effectiveness, and needs satisfaction: new options for designing climate policies

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Fairness, effectiveness, and needs satisfaction: new options for designing climate policies

Milena Büchs[1],[*] ![ORCID], Diana Ivanova[1] ![ORCID] and Sylke V Schnepf[2] ![ORCID]

1   Sustainability Research Institute, University of Leeds, Leeds, United Kingdom
2   European Commission, Joint Research Centre, Ispra, Italy
*   Author to whom any correspondence should be addressed.

E-mail: m.m.buchs@leeds.ac.uk

Abstract

Financial compensations are often proposed to address regressive distributional impacts of carbon taxes. While financial compensations have shown to benefit vulnerable groups distributionally, little is known about their impacts on emission reduction or needs satisfaction. A potential problem with cash compensations is that if households spend this money back into the economy while no additional decarbonisation policies are implemented, emission reductions that arose from the tax may at least partly be reversed. In this letter, we compare the emission savings and impacts on fuel and transport poverty of two compensation options for carbon taxes in 27 European countries. The first option consists of equal per capita rebates for home energy and motor fuel taxes. The second option is the provision of universal green vouchers for renewable electricity and public transport, supported by additional investments in green infrastructures to meet increased demand for such green consumption. Results show that the first option of tax rebates only supports small emission reductions. In contrast, universal green vouchers with expanded green infrastructures would reduce home energy emissions by 92.3 $MtCO_2e$ or 13.4%, and motor fuel emissions by 177.5 $MtCO_2e$ or 23.8%. If green vouchers and infrastructure were provided without a prior tax, emission savings would be slightly lower compared to the 'tax and voucher' scheme, but fuel and transport poverty would drop by 4.1 and 2.2 percentage points, respectively. In contrast, taxes with rebates would increase fuel and transport poverty by 4.1 and 1.8 percentage points. These findings demonstrate that it is important to take environmental and energy poverty impacts of compensations for unfair distributional impacts of climate policies into account at the design stage. Such compensation measures can achieve higher emission reductions and reduce energy poverty if they involve an expansion of the provision of green goods and services, and if everyone is given fair access to these goods and services.

1. Introduction

Climate policies need to be not only environmentally effective but also fulfil social objectives such as needs satisfaction for all, and a fair distribution of costs and benefits. Prior research has shown that climate policies that increase the price of necessities, e.g. carbon taxes on home energy, tend to have regressive effects in European countries [1, 2][3]. Here,

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3 Schemes such as the European Emission Trading Scheme which applies to corporations also had indirect regressive effects, especially in its early phase in which it distributed allowances to large emitters for free [37].

regressiveness can be defined as financial impacts that burden low income households more than richer households relative to their income. Rising prices for necessities can also increase various forms of poverty and hence compromise needs satisfaction. This can be considered unfair since poorer households have much lower emission footprints than well-situated households and are hence less responsible for climate change. Efforts need to be made to prevent unfair impacts of climate policies, for instance by compensating vulnerable households for undue burdens. This paper examines for the first time emission reductions, distributional impacts, and impacts on energy

poverty from different compensation options to contribute to this debate.

A range of studies analyse the distributional impacts of financial compensations for regressive carbon taxes, including equal per capita tax rebates, tradable equal per capita carbon or energy allowances, or cash compensations delivered through the tax and benefit system. Equal per capita tax rebates [3–6] and tradable allowances [4, 7–9] have both been shown to effectively compensate poorer households, and they are near equivalent in distributional terms at a given price of carbon or energy. Compensations delivered through the tax and benefit system have shown to be less effective in compensating poorer households than equal per capita schemes [3, 6, 10–17]. They also have the disadvantage that means-tested benefits can be associated with stigma, higher administrative cost, and lower uptake than universal per capita schemes. Studies on these compensatory mechanisms have focused on distributional effects. To our knowledge, there has not yet been a comparative assessment of their carbon saving potential or their capacity to address people's needs satisfaction, for instance through a reduction of fuel or transport poverty. It is important to apply all three criteria—distributional fairness, emission reduction, and needs satisfaction—in evaluations of climate policies because there are potential tensions between environmental and social objectives as is the case if carbon or energy taxes have regressive distributional impacts. Furthermore, while fair distribution and needs satisfaction can be positively associated, they are not identical. For instance, even if basic needs for all are fulfilled, high levels of inequality could exist; and conversely, certain needs might remain unaddressed even in scenarios with highly equal distributions of income or other resources.

A potential problem with cash compensations for carbon taxes is that if households spend this money back into the economy without additional decarbonisation policies being implemented, emission savings from the carbon taxes may at least partly be negated. In this letter, we compare the emission savings and impacts on fuel and transport poverty of two compensation options for 27 European countries. The first option consists of equal per capita cash rebates for home energy and motor fuel taxes. The second option is the provision of universal green vouchers for renewable electricity and public transport, supported by additional investments in green infrastructures to meet increased demand for such green consumption. These green vouchers are equivalent in value to the tax rebates, and 'universal' in the sense that they are given to everyone in society independent of income or other conditions. The provision of vouchers would aim to make at least a partial contribution to satisfy people's basic needs as they would allow free usage of a limited amount of the services provided by green infrastructures (renewable electricity and public transport).

Universal green vouchers would be publicly funded, in our example through carbon tax revenues, but other types of public funding are possible.

Before we explain the study design, we briefly explain how green vouchers could work in practice. Traditionally, vouchers are tokens that people can use to purchase a good or service. However, since nowadays online payment systems are widely available, 'vouchers' could be given to people through online accounts, in this case for electricity and public transport. For instance, electricity providers could be obliged to provide a set amount of free electricity to each of their customers (based on the number of people in a household), and only start charging them once that basic amount is exhausted. Similarly, every person could be given an online account for public transport journeys. They could tap a card or mobile phone every time they enter a bus, train or underground, automatically drawing the payment from the account until it is exhausted, from which onwards that person would need to top up their account. Such online payment systems could also increase the use of universal vouchers since people are automatically 'opted in'.

In addition, universal green vouchers could allow interpersonal trading so that people who do not require their full allocation can sell the surplus to people who require a higher amount. Interpersonal trading would increase flexibility, cater for different levels of needs, and avoid overconsumption. The distributional and environmental impacts of a tradable scheme would be equivalent to the scheme we estimate here (at a given carbon price) because those who sell simply exchange their 'voucher' for cash. Those who buy additional vouchers can increase their usage of free renewable electricity or public transport. At the carbon price that we assume in our model, 6.7% of households receive electricity vouchers whose value exceeds their pre-tax expenditure on electricity, and 8.4% of households receive public transport vouchers that exceed their pre-tax expenditure on motor fuel and public transport, indicating the scope for inter-personal trading. Scope may be higher than that for public transport vouchers as people in rural areas (49% of the sample) who have poor public transport access may also prefer cash compensation to purchase motor fuels. In rural areas, alternative voucher options could be made available, for instance, vouchers could be swapped for renewable electricity vouchers, or they could be used towards the purchase of low emission vehicles or electric car club memberships.

This study assumes that the provision of green vouchers would need to be accompanied by an expansion of green infrastructures to ensure sufficient supply. Expanding green infrastructures changes the average carbon footprint of consumption in society, while 'vouchers' give people the right to limited free usage of the services that these infrastructures provide. In addition to government expenditure on

the vouchers, further investments would be required to expand renewable electricity generation and public transport to cover the new demand created by the vouchers. Such additional investments are not assumed in the tax and 'tax and rebate' models. This means that the higher emission savings from the voucher schemes in our model result from the expansion of green infrastructures, they are not an inherent feature of green vouchers per se. In principle, cash compensation schemes could also be combined with additional decarbonisation investments, but the purpose of this study is to examine the difference between the two scenarios.

In Europe, two main carbon pricing mechanisms exist: (a) the European Union Emission Trading Scheme (EU ETS) and national emission trading schemes, and (b) national level carbon or energy taxes. Taxes on energy such as electricity or gas are often regarded as implicit carbon taxes. Emission trading schemes and carbon or energy taxes exist side by side, and most European countries have carbon or energy taxes in place [18]. National carbon or energy taxes like the ones modelled in this paper are hence compatible with the EU ETS, and the EU recommends the adoption of higher national carbon or energy taxes in its European Green Deal [19].

The letter makes a novel contribution to the literature by comparing distributional justice (fairness), emission reduction and needs satisfaction of options for compensating people for regressive impacts of carbon taxes that differ in the mode of compensation (cash vs in-kind) and levels of government investment into green infrastructures.

2. Materials and methods

2.1. Data
The analysis is based on data from the new 2015 European Household Budget Surveys (HBSs) and Exiobase. The 2015 HBS provides detailed household expenditure in Euros for 23 European countries, harmonised and disseminated by Eurostat. We add to the analysis four countries from the 2010 HBS dataset that were no longer included in 2015 (Malta, Portugal, Slovenia and the UK). The total sample size for the 27 countries is 275 614 households. We combine detailed expenditure variables into broader categories for home energy (including electricity, gas, other fuels such as coal, coke and bottled gas) and motor fuels. Household characteristics such as the number of adults and children, age, gender, and employment status of the household representative are created from the HBS member files. Household weights provided in the HBS are applied throughout to account for sampling and response bias.

We use data from the multiregional input-output analysis Exiobase dataset (version 3.7) to estimate annual greenhouse gas emissions per household (in CO_2-equivalents) [20]. We apply the global warming

potential (GWP100) metric [21] to convert different greenhouse gases (GHG) (carbon dioxide, methane, nitrous oxide and sulphur hexafluoride) to kilograms of CO_2-equivalents for 2015 (2010 for the UK, MT, PT and SI). Exiobase covers high sectoral detail (200 products), 49 countries (including all EU countries) and rest-of-the-world regions, as well as a wide range of environmental accounts [20, 22, 23]. We use this data to estimate GHG emissions for the expenditure categories as defined above for each country in 2015/0 in Exiobase, based on 2015/0 purchasers' prices. We then divide total emissions from Exiobase by total HBS expenditure per category and country to generate emission factors in kg CO_2e/Euro. These factors are then multiplied by household expenditure and converted to tonnes of CO_2e per household. Since expenditure in the HBS is provided in Euros, this method corrects for differences in price levels between countries.

2.2. Microsimulation of four policy options
This study estimates emission savings, distributional effects and impacts on fuel and transport poverty of four policy options: a carbon tax and three compensation models: 'tax and rebate', 'tax and voucher', and 'voucher only' (figure 1). All models assume the same tax rate and the same value of per capita tax rebates and green vouchers.

The level of the carbon tax is equal to €80 per tonne of CO_2e in international prices, and is adjusted to national price levels by making use of price level indices for final household consumption. This tax rate was chosen because it lies within the range of carbon prices of $75–100 per tonne of CO_2e recently recommended by experts for achieving carbon reduction targets [24, 25]. In two sub-models, the tax is applied to home energy GHG (which include emissions from electricity, gas and other heating fuels) and motor fuel GHG. Estimation of tax impacts happens in two stages. In 'stage 1', we apply income elasticities per income quintile to estimate the reduction in emissions due to reductions in real income that households would experience as a result of the tax (supplementary table 3 (available online at stacks.iop.org/ERL/16/124026/mmedia)). In 'stage 2', the carbon tax is applied to the reduced emissions to estimate distributional impacts of the tax burden over income quintiles, as well as changes in fuel and transport poverty.

The second 'tax and rebate' model examines impacts of a carbon tax with revenue neutral tax rebates. Rebates are based on a 100% re-allocation of the tax revenue from the baseline model on an equal per adult and equal per child basis (children receive 50% of the per-adult rebate, to avoid disadvantaging households with children [7, 26]). Changes in emissions are estimated based on the net gain/loss from the 'stage 1' tax rebate and income elasticities, and distributional implications are

Figure 1. Microsimulation policy models.
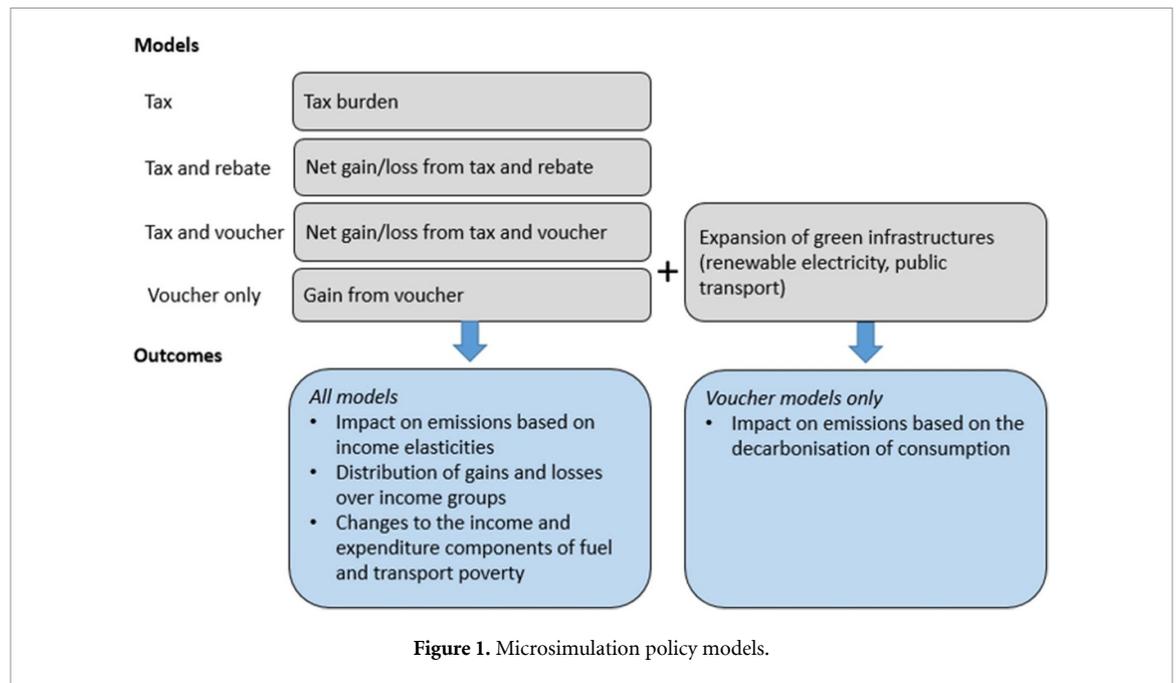
estimated based on net gain/loss from the 'stage 2' tax rebate.

The third 'tax and voucher' model examines impacts of in-kind vouchers instead of cash rebates as a compensation for carbon tax burdens. The voucher amounts and their allocation are identical to the tax rebates which means these two schemes are treated as distributionally equivalent in this study. Doing so enables us to compare the differences in emission reductions and fuel/transport poverty between 'tax and rebate' and 'tax and voucher' schemes. Emission reductions in the voucher scheme are estimated by assuming that households now consume electricity from renewable sources for the amount that is covered by the voucher. We also assume that renewable electricity generation has increased to cover demand, supported by additional government investments (on top of the funding for the vouchers), and that this renewable electricity has a carbon footprint of 4.2% compared to average grid electricity in 2015 (see supplementary material for further details). For the travel model, we assume that households use the public transport vouchers to cover trips that they previously did by car, and that emissions from public transport have 25% of the carbon footprint of car travel. As above, this model anticipates that additional public investments have expanded public transport capacity to meet demand.

The fourth 'voucher only' model distributes green vouchers to households in the same way as model three but does not apply a prior tax. Increases in consumption in response to the receipt of vouchers are deducted from the emission reductions of the vouchers schemes in model 3. Distributional implications are calculated based on the gain in income that households receive from the vouchers. Model 4 is the most expensive of the four models because governments

would have to use additional funds to pay for the vouchers, on top of the investments into green infrastructure.

In all models, impacts on needs satisfaction are examined by estimating changes in fuel and transport poverty based on Hills' 'Low-Income High-Cost' approach [27] for fuel poverty and Mattioli *et al*'s adoption of it to the affordability dimension of transport poverty [28, 29] (see supplementary material for further details).

2.3. Limitations

This study faces several limitations (see supplementary material for further details). There are limitations related to the data quality of the HBS, for instance with regard to harmonisation across countries [30, 31]. The policy modelling is limited by the fact that only income elasticities but not price elasticities and related substitution effects are considered; that we cannot account for regional fuel price variations within countries (only price variation across countries); and that the estimates of changes in fuel and transport poverty are shaped by the 'low income, high cost' [27] definition applied in this study. The modelling is also limited because we cannot estimate the impact of barriers to distribute tax rebates to every single household, or regarding the take-up of the vouchers. Take-up might be lower than assumed in our models, especially for public transport vouchers (but see the supplementary material document for a discussion of addressing low uptake). In addition, we cannot take into account possible welfare losses related to the tradability of vouchers, and their unequal distribution across social groups. Estimating the cost of expanding renewable electricity generation and public transport provision is also limited, as are estimations of savings from government

support for high carbon industries or from environmental and social welfare gains that result from lower emissions. Finally, the modelling of changes in emissions based on income elasticities rests on neoclassical theories of consumer behaviour. However, behavioural responses are likely to be shaped by other factors too as discussed in social-psychological and social practices literatures [32, 33], and broader heterodox economics frameworks are required to explain consumer and producer responses to carbon taxes.

3. Results

3.1. Emission reduction
In response to a €80 tax on carbon, home energy emissions would reduce by a total of 8.4 $MtCO_2e$ or 1.21% of home energy emissions, and motor fuel emissions by 11.6 $MtCO_2e$ or 1.56% of motor fuel emissions across all 27 countries (figure 2). These findings are broadly consistent with other studies which find low or even insignificant rates of emission reduction in response to carbon taxes (e.g. Haites [34] covers 18 mostly European countries in a systematic review, and Lin and Li [35] for five Northern European countries).

The 'tax and rebate' schemes cancel out a considerable proportion of the emission savings from the taxes because they redistribute the tax revenue to households which is then spent back into the economy. While the initial tax should incentivise consumers to reduce consumption or switch to lower carbon products, it is plausible to assume that tax rebates dampen this incentive, especially where demand is relatively inelastic such as for electricity or motor fuels. Results still show a small reduction of emissions because the new spending by low income households who tend to gain from the rebates is lower than the emission reductions from richer households who tend to have net losses from the rebates. Home energy emissions are reduced by 2.3 $MtCO_2e$ or 0.33%, and motor fuel emissions by 5.3 $MtCO_2e$ or 0.71%. The 'tax and rebate' models do not assume additional government investments into green infrastructures. In the presence of such investments, emission reductions could be higher for tax rebate schemes because rebates could be spent on low carbon goods and services that replace their high carbon counterparts.

For the 'tax and voucher' model, we assume that the consumption of regular electricity is replaced with renewable electricity, and motor fuel travel by public transport, supported by prior government investments into such green infrastructures. We find that the free renewable electricity vouchers would save 92.3 $MtCO_2e$ or 13.36% of initial home energy and 31.58% of initial electricity GHG emissions for all 27 countries. Public transport vouchers would save 177.5 $MtCO_2e$ or 23.8% of the initial amount of motor fuel emissions. The vouchers facilitate fair access to these green consumption options in society.

The 'voucher only' model also assumes that motor fuel and regular electricity consumption are replaced with greener options due to additional government investments. Since there is no prior tax, people's incomes and consumption are assumed to increase. However, since this is only a small overall proportion of income while carbon intensive consumption would be replaced with green consumption, total emission reductions are still considerable, with 84.0 $MtCO_2e$ or 12.2% of initial home energy and 27.8% of initial electricity emissions; and 166.0 $MtCO_2e$ or 22.3% of initial motor fuel emissions.
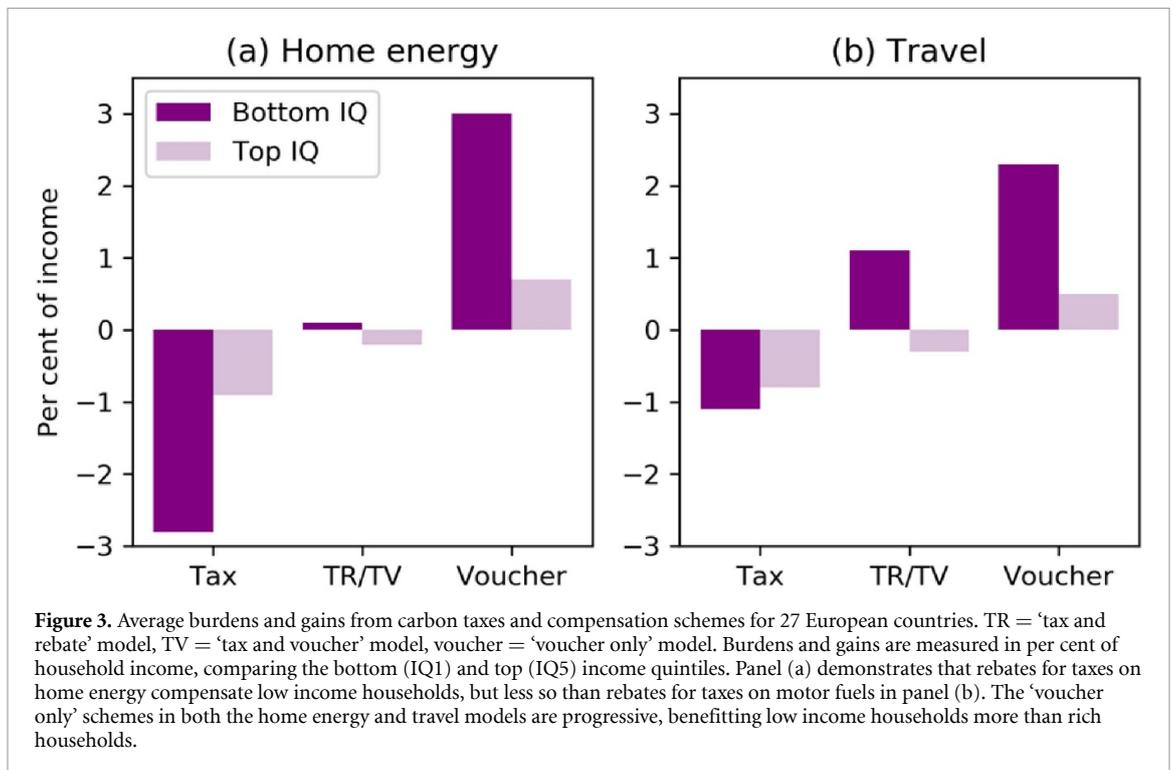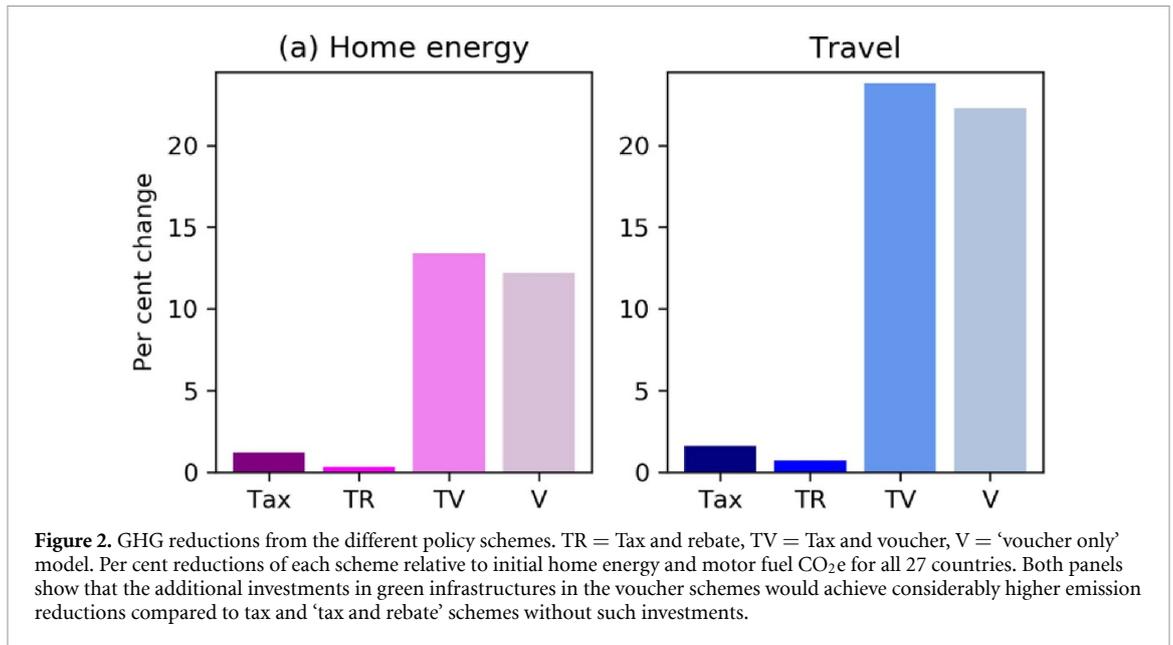
3.2. Distributional impacts
Results show that carbon taxes tend to be regressive, and that all of the compensation schemes tend to benefit low income households. However, the 'voucher only' scheme is more redistributive and generates the highest gains for low income households compared to the 'tax and rebate' and 'tax and voucher' schemes (supplementary table 4).

Taxes on home energy are more regressive than taxes on motor fuels. In all 27 countries, households in the lowest income quintile bear statistically significant higher home energy tax burdens than those in the top income quintile (average −2.8% vs −0.9% of annual income). A tax on motor fuel also puts a slightly higher tax burden on households in the lowest income quintile compared to the highest income quintile (−1.1% of income compared to −0.8% of income, still statistically significant at $p < 0.001$). Note, however, that a tax on motor fuel was progressive or distributionally neutral in several, especially Eastern European countries (Bulgaria, Croatia, Czech Republic, Greece, Hungary, Lithuania, Latvia, Poland, and Romania).

On average, households in the bottom income quintile receive a net gain from tax rebates with 0.1% and 1.1% of annual income for home energy and motor fuel emission taxes respectively, while those in the top income quintile face a net loss of −0.2% and −0.3% of income for home energy and motor fuel schemes respectively.

In countries where taxes on home energy are most regressive, tax rebates do not fully compensate low income households or reduce income inequality. Rebates for motor fuel taxes compensate low income households and reduce income inequality in all countries (figure 3 and supplementary table 4). However, there is wide variation across households in terms of net gains and losses from the rebates, depending on initial emissions, household size and composition. For home energy tax rebates, 62.1% of households in the bottom income quintile receive a net gain, compared to 41.5% in the top income quintile. In the motor fuel model, the respective figures are 80.7% vs 40.4%. The more regressive the impact of the initial tax is, the higher is the share of low income

Figure 2. GHG reductions from the different policy schemes. TR = Tax and rebate, TV = Tax and voucher, V = 'voucher only' model. Per cent reductions of each scheme relative to initial home energy and motor fuel CO_2e for all 27 countries. Both panels show that the additional investments in green infrastructures in the voucher schemes would achieve considerably higher emission reductions compared to tax and 'tax and rebate' schemes without such investments.

Figure 3. Average burdens and gains from carbon taxes and compensation schemes for 27 European countries. TR = 'tax and rebate' model, TV = 'tax and voucher' model, voucher = 'voucher only' model. Burdens and gains are measured in per cent of household income, comparing the bottom (IQ1) and top (IQ5) income quintiles. Panel (a) demonstrates that rebates for taxes on home energy compensate low income households, but less so than rebates for taxes on motor fuels in panel (b). The 'voucher only' schemes in both the home energy and travel models are progressive, benefitting low income households more than rich households.
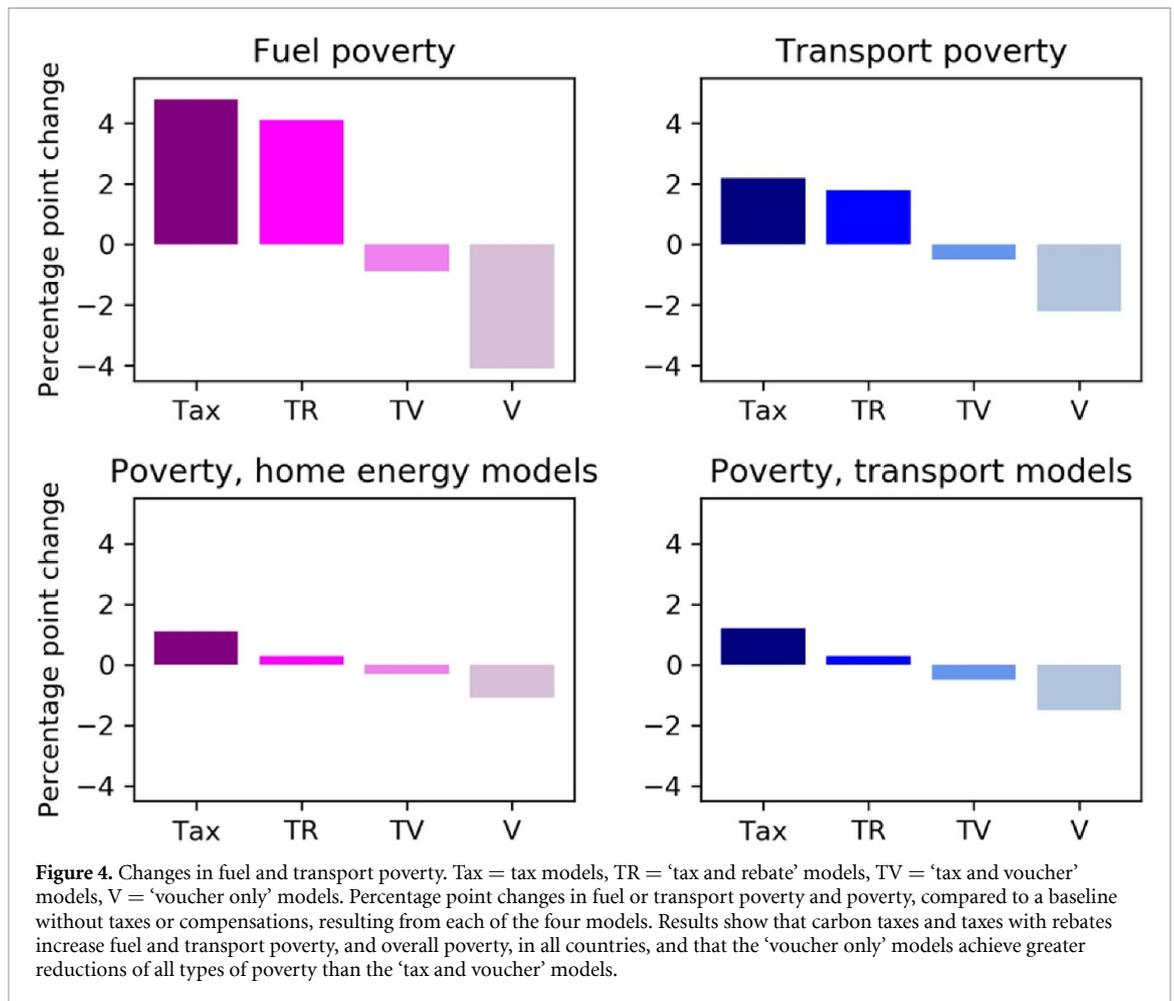
households that face a net loss from the tax rebate and vice versa. The 'tax and rebate' and 'tax and voucher' schemes are distributionally equivalent because the rebates and vouchers have the same value in the calculations to make the schemes comparable.

In the 'voucher only' scheme, all households gain in real terms because they receive vouchers but do not pay a tax. In all countries, households in the bottom income quintile gain more from the scheme as a percentage of income compared to households in the highest income quintile, with a 3.0% vs 0.7% gain for renewable electricity vouchers, and a 2.3% vs 0.5% gain for public transport vouchers respectively (figure 3 and supplementary table 4).

Distributional impacts are also reflected in changes in the income ratio between the top 90th and the bottom 10th percentile. The tax on home energy increases the ratio by 1% (i.e. it increases inequality), the tax on motor fuel is neutral, and all of the compensation schemes slightly decrease the income ratio (by 0.3% in the home energy 'tax and rebate' scheme and 1.4%–1.5% in all other schemes).

3.3. Fuel and transport poverty
Fuel and transport poverty are important indicators of compromised needs satisfaction. We examine impacts of the four schemes on both, based on the 'low income, high cost' approach as defined by Hills

Figure 4. Changes in fuel and transport poverty. Tax = tax models, TR = 'tax and rebate' models, TV = 'tax and voucher' models, V = 'voucher only' models. Percentage point changes in fuel or transport poverty and poverty, compared to a baseline without taxes or compensations, resulting from each of the four models. Results show that carbon taxes and taxes with rebates increase fuel and transport poverty, and overall poverty, in all countries, and that the 'voucher only' models achieve greater reductions of all types of poverty than the 'tax and voucher' models.

for home energy [27] and Mattioli *et al* for transport [28]. According to this definition, households are 'fuel poor' if they spend more than the equivalised median spending on home energy and if their income minus equivalised home energy expenditure is below 60% of median income after housing cost (rent and mortgages). The definition of transport affordability which we focus on here as a measure of transport poverty follows the definition of fuel poverty except that the cost threshold is set at twice the median share of income spent on motor fuels [28]. To be able to examine policy impacts compared to the initial baseline, we present here changes in fuel and transport poverty based on constant expenditure and income thresholds. See supplementary table 2 for an analysis in which fuel expenditure thresholds are re-calculated in each model.
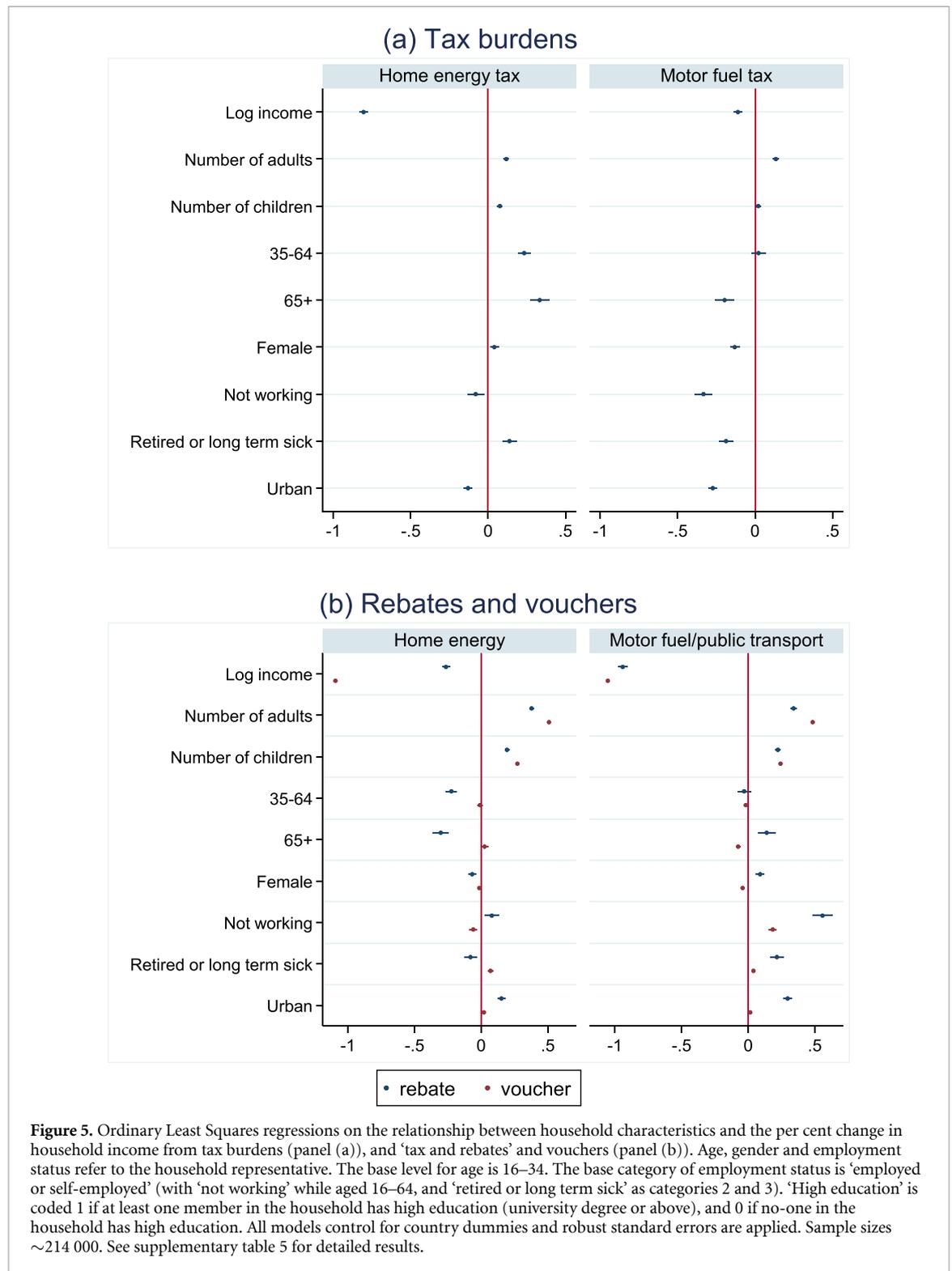
The four schemes have different impacts on fuel and transport poverty (figure 4). The tax and 'tax and rebate' schemes increase fuel and transport poverty in all countries. The rebate schemes are not effective in reversing increases in fuel and transport poverty caused by carbon taxes because they do not tackle increased home energy or transport expenditure. The 'tax and voucher' schemes slightly reduce fuel and transport poverty. The 'voucher only' scheme is

the only one that improves needs satisfaction in all countries.

The home energy tax increases fuel poverty by an average 4.8 percentage points (from an initial 10.7% to 15.5%) across all 27 countries. The 'tax and rebate' scheme still increases fuel poverty by an average 4.1 percentage points (to 14.8%) compared to the base model. The renewable electricity 'tax and voucher' scheme reduces fuel poverty by 0.9 percentage points (down to 9.8%) and the 'voucher only' schemes reduces fuel poverty by 4.1 percentage points (down to 6.6%).

The motor fuel tax increases transport poverty by an average 2.2 percentage points compared to the base line scenario (from 8.7% to 10.9%). The motor fuel 'tax and rebate' scheme still increases transport poverty by 1.8 percentage points compared to the base line (to an overall 10.5%), and the free public transport 'tax and voucher' scheme reduces it by 0.5 percentage points (down to 8.2%). The 'voucher only' scheme would reduce transport poverty by 2.2 percentage points compared to the base scenario, down to an overall 6.5%.

We also calculate changes in poverty in response to the four schemes, where poverty is defined as income after housing cost and home energy or motor

Figure 5. Ordinary Least Squares regressions on the relationship between household characteristics and the per cent change in household income from tax burdens (panel (a)), and 'tax and rebates' and vouchers (panel (b)). Age, gender and employment status refer to the household representative. The base level for age is 16–34. The base category of employment status is 'employed or self-employed' (with 'not working' while aged 16–64, and 'retired or long term sick' as categories 2 and 3). 'High education' is coded 1 if at least one member in the household has high education (university degree or above), and 0 if no-one in the household has high education. All models control for country dummies and robust standard errors are applied. Sample sizes ~214 000. See supplementary table 5 for detailed results.

fuel expenditure respectively. We see a similar pattern where the 'tax and rebate' schemes slightly increase poverty compared to the baseline, and where the 'voucher only' model leads to greater poverty reductions than the 'tax and voucher' models (see figure 4).

3.4. Revenue and cost of schemes
After taking changes in consumption into account, a (price level adjusted) tax of €80 per tonne of

CO_2e would generate a total revenue across all countries of €51.3bn for home energy (0.37% of Gross Domestic Product (GDP)) and €57.0bn for motor fuels (0.42% of GDP). The 'tax and rebate' and 'tax and voucher' schemes are revenue neutral because 100% of the tax revenue is redistributed to households. The 'voucher only' scheme requires spending of €51.3bn (0.38% of GDP) for renewable electricity vouchers, and €57.01bn (0.42% of GDP) for public

transport vouchers that is not covered by a prior carbon tax (where the amount of spending is equivalent in value to the tax revenues above).

Both voucher schemes require additional government spending to expand renewable electricity production and the public transport system. We estimate that expanding renewable electricity generation to meet additional demand created by the vouchers would cost around €38.1bn (0.26% of GDP), and that expanding public transport would cost around €38.4bn (0.27% of GDP) (see supplementary material for details). These sums only constitute small proportions of GDP. Furthermore, it is important to note that these costs could at least be partly counter-balanced by savings and welfare gains in other areas. For instance, spending on high carbon infrastructures and industries could be reduced and provide a large part of the funding for green infrastructures. There would also be welfare gains such as improved health and wellbeing due to better air quality and reduced climate change impacts, as well as lower fuel and transport poverty. Government expenditure in response to climate change impacts such as flooding, storms, heat waves and fires, or coastal erosion would also reduce in the longer term. The type of funding chosen for expanding green infrastructures will have distributional impacts, e.g. whether funding is based on progressive income or wealth taxes, regressive value added tax, government borrowing or public money creation.

3.5. Household characteristics

We conduct ordinary least squares regressions to examine which types of households lose or gain more in the tax, 'tax and rebate'/'tax and voucher' (here treated as one model as they are distributionally equivalent) and 'voucher only' models. Panel (a) of figure 5 shows that tax burdens decrease with increasing household income, confirming the regressiveness of carbon taxes. Tax burdens increase with household size but are smaller for households in urban areas. There are important differences between taxes on home energy or motor fuel emissions: while households with representatives aged 65 and over bear higher tax burdens for home energy taxes, they bear lower tax burdens for motor fuel emission taxes. The same applies to female-headed households and households whose representatives are retired or long-term sick.

Panel (b) shows that high income households gain less from tax rebates and vouchers than low income households, confirming the progressive nature of these instruments. 'Tax and rebates'/'tax and vouchers' for home energy do not fully compensate households with older, female or retired/sick representatives, but these groups do not tend to lose out or are even slightly better off in the 'voucher only' models.

4. Conclusion

This study examines the emission savings, distributional impacts, and impacts on fuel and transport poverty from compensation options for regressive impacts of carbon taxes. To achieve fairer outcomes, greater public support, and hence more effective results, climate policies should be designed based on criteria of distributional fairness, capacity to satisfy basic needs and environmental effectiveness in conjunction. Based on these criteria, we compare carbon tax and 'tax and rebate' scenarios, in which technological/infrastructure changes are left to the market, to scenarios where governments directly invest in green infrastructures to facilitate a shift to green consumption and provide everyone in society with the right to free access to these infrastructures through vouchers which act as an in-kind compensation for tax burdens.

The findings show relatively low emission reductions from the tax, and the 'tax and rebate' models. These findings are consistent with the previous literature on the impact of carbon or energy taxes on emissions [34–36]. Carbon taxes are usually assumed to incentivise consumers to switch to low carbon products and services. However, this only works if there are low carbon alternatives available with sufficiently large price differentials between high and low carbon products, and if companies expand production and provision of low carbon products to meet demand. Several factors, including inelasticity of demand, imperfect information and habits, the concentration of market power, and technological and institutional path dependencies might be barriers for markets to respond in ways expected by neoclassical economic theory, and hence reduce the capacity of carbon taxes on their own to reduce emissions.

The compensation models in our study provide households with the cash or in-kind equivalent of 25.5% of initial electricity expenditure and 25.9% of initial motor fuel expenditure. If these proportions of consumption can be shifted to low carbon options through new investments in green infrastructures, we estimate that additional emissions savings of 13.4% for home energy and 23.8% for travel could be made in the presence of a carbon tax, at the cost of 0.26% and 0.25% of GDP respectively to expand renewable electricity generation and public transport. The cost for green infrastructure could be at least partly counter-balanced by reduced spending on high carbon infrastructures, health and wellbeing impacts of high carbon societies, as well as infrastructure damage and other negative economic impacts of climate change.

Our study confirms that universal, equal per capita tax rebates or green vouchers tend to compensate poorer households for regressive effects and decrease income inequality. Since taxes on home energy are

more regressive than taxes on motor fuels, these compensation options have greater progressive distributional effects in response to motor fuel taxes compared to home energy taxes.

Providing households with free access to renewable electricity or public transport through vouchers instead of compensating with cash would also reduce fuel and transport poverty, and overall poverty compared to a baseline without any policy intervention. At least based on the 'low income, high cost' definition of fuel and transport poverty, cash compensation on its own cannot reverse increases in these forms of poverty that result from taxes.

Our results show that compensation schemes for carbon taxes on necessities can neutralise regressive effects, but they are unlikely to speed up carbon reduction compared to existing trends, unless additional efforts are made to decarbonise the provision of consumption. Universal green voucher schemes could ensure that everyone in society has equal access to basic levels of low carbon consumption.

Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

Acknowledgments

Author contributions

M B designed the study, conducted the analysis and wrote the paper. D I and M B calculated the consumption-based emission figures based on Exiobase, and D I and S V S provided advice and comments on drafts.

Conflict of interest

The authors do not have any competing interests to declare.

Ethics statement

The study uses data from the 2015 European Household Budget Survey. We have permission to use the data from the European Commission, and the data are fully anonymised.

ORCID iDs

Milena Büchs ⬤ https://orcid.org/0000-0001-6304-3196
Diana Ivanova ⬤ https://orcid.org/0000-0002-3890-481X
Sylke V Schnepf ⬤ https://orcid.org/0000-0003-0768-5682

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