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Emissions inequality: Disparities in income, expenditure, and the carbon footprint in Austria

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ABSTRACT

The social consequences of carbon taxation are closely related to the income and expenditure patterns of private households. This paper combines the national Household Budget Survey with EXIOBASE3 emissions data to analyse the distribution of the carbon footprint and differences in the exposure to carbon taxation in Austria. The results indicate a strong variation in greenhouse gas (CO_2e) emissions along the income distribution, with the top income decile emitting 4.1 times more than the bottom income decile. We distinguish between local, EU-based, and rest-of-the-world (RoW) emissions and study how various approaches to CO_2e taxation would affect households with different incomes. Finally, we compare the implications of taxing direct domestic emissions only versus taxing the carbon footprint and find socio-demographic factors that explain why some households have higher tax-to-income ratios. Socially balanced carbon mitigation policies should focus on these emitters as they might be particularly exposed to CO_2e taxation.

1. Introduction

As the consequences and long-term implications of the deepening climate crisis are becoming more and more apparent, a coalition of environmental movements, researchers and members of the political domain are calling for ambitious and lasting measures to achieve sustainable economies and societies in the future. From an economic point of view, an increase in the price of carbon and the incentives involved are seen as the most important lever to reduce the demand for fossil energy sources. The key assumption here is that agents actually have the capacity to react to the price signal. However, some parts of the population may lack the economic resources to adjust in the short term by investing in a new heating system or an electric car. Not only would this result in an overall reduction of the effectiveness of the intervention, but it would also cause unintended social ramifications. Such households may feel trapped and left behind as they are confronted with an extended period of increased financial burdens and reduced consumption opportunities.

Only recently, the environmental crisis and (lacking) countermeasures have unleashed social protests like the Fridays For Future movement and the Yellow Vests in France, expressing the importance of considering social consequences in the fight against climate change. Measures that link consumption taxes to CO_2 emissions have been discussed as being particularly controversial. Indeed, the distributive effects of such taxes are not evident and have been subject to speculation.

The call for a significant reduction in greenhouse gas (GHG) emissions has been addressed with several policy responses. Prominent proposals in the European debate are the carbon border tax, the CO_2 tax and adaptions of the European Union Emissions Trading System (EU ETS). The idea behind the carbon border tax is to prevent carbon leakage, which means the relocation of carbon-intensive production to non-EU countries with laxer jurisdictions, and is thus focused on indirect emissions embodied in products. A CO_2 (or carbon) tax, in contrast, is levied on the carbon content of fuels and thus is basically a consumption tax linked to direct domestic emissions. Finally, the EU ETS is a trading system for GHG emissions and aims to gradually reduce production-based emissions in the EU countries. All these measures might eventually lead to an increase in the prices of carbon-intensive consumption goods for private households although through different channels.

The price effects of these carbon mitigation policies are intended to

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have an impact on prevailing consumption patterns. The extent to which individual households are affected depends on the carbon content of their consumption basket, which differs across the income distribution. This paper analyses the nexus between income distribution, consumption expenditure and resultant CO_2e (all greenhouse gases in equivalent tonnes of CO_2) emissions by combining the Austrian Household Budget Survey (HBS) for 2009/10 with the EXIOBASE3 database, which provides emission intensities by consumption categories. EXIOBASE3 provides information on direct emissions that originate from the consumption of goods, as well as indirect emissions that are embodied in the production of goods and services for household consumption, corporate investment and government spending. Here, we focus on household final consumption which accounts for approximately two thirds of the national footprint (Steininger et al., 2018). The merged data set enables us to study household CO_2e emissions across the income distribution and to analyse differences in the exposure to carbon mitigation policies for Austrian households. Since we can distinguish emissions by their origin between direct and indirect domestic, indirect EU-based and rest of the world (RoW), we assess how carbon tax proposals would affect households along the income distribution. By assuming a CO_2e price of €100 per metric ton, we compare the implications of taxing direct domestic emissions only versus taxing the entire household carbon footprint. We identify potentially overburdened households with high tax-to-income ratios and are able to show that there are differences in the household characteristics that explain the exposure to taxation of domestic emissions vis-à-vis the more comprehensive carbon footprint.

Our approach relates to the literature that explicitly considers the carbon footprint, which includes all emissions embodied in consumption goods regardless of their origin (Isaksen and Narbel, 2017; Weber and Matthews, 2008), rather than domestic emissions only (Roca and Serrano, 2007). In addition, our data set enables us to identify households that would be particularly affected by policies raising the cost of carbon-intensive goods and services.

This paper adds the case of Austria to the literature on the nexus between economic and ecological inequality (Kerkhof et al., 2009a; Kerkhof et al., 2009b; Gough, 2013; Büchs and Schnepf, 2013; Steen-Olsen et al., 2016) and mainly asks three questions. First, what is the relationship between the distribution of household income, consumption expenditure and CO_2e emissions? Second, how does the origin of emissions differ across the income distribution? Third, who would be particularly exposed to policies that increase the prices of carbon-intensive goods and services? Empirical evidence to answer these questions is key to understanding the social consequences of carbon mitigation policies and to ensuring broad support for such measures among the population.

2. Related literature

Research on household environmental impacts goes back to the mid-1970s, when input-output data on direct and indirect energy requirements were linked to household-level data for the US (Herendeen and Tanaka, 1976) and Norway (Herendeen, 1978). This gave rise to an increasing number of studies connecting surveys of private household expenditure with all kinds of environmental indicators and using a variety of different databases focusing on individual countries or regions, or comparisons between them (for extensive reviews, see Zhang et al., 2015; Di Donato et al., 2015; Pottier et al., 2021).

A number of prior studies stress the distribution of environmental footprints as well as heterogeneous effects of environmental policies on household groups. So far, the consensus is that measures of environmental pressure, household expenditure and household income are positively correlated across Europe, for instance for Spain (Roca and Serrano, 2007), Norway (Steen-Olsen et al., 2016; Isaksen and Narbel, 2017), Switzerland (Girod and De Haan, 2010), the UK (Baiocchi et al., 2010; Büchs and Schnepf, 2013) and Barcelona (Bel and Rosell, 2017), as well as in a comparative study for the Netherlands, the UK, Sweden and Norway (Kerkhof et al., 2009a; Kerkhof et al., 2009b), and for 26 European Union countries (Ivanova and Wood, 2020). Similar studies exist on an international scale for the US (Weber and Matthews, 2008), Indonesia (Irfany and Klasen, 2016), the Philippines (Seriño and Klasen, 2015), China (Golley and Meng, 2012; Wiedenhofer et al., 2017; Zhang et al., 2017) and for 86 highly industrialized and developing countries (Oswald et al., 2020).

Nevertheless, the literature is inconclusive about the exact proportionality of environmental pressure, household expenditure and household income. While some papers find that the carbon footprint increases more than would be proportional with income and expenditure (Oswald et al., 2020; Golley and Meng, 2012), others show that emissions rise but with slower rates than income (Ivanova et al., 2017; Weber and Matthews, 2008) or suggest a linear relationship (Isaksen and Narbel, 2017). While evidence exists for various countries, the case of Austria with a detailed focus on the nexus between economic and ecological inequality is still missing (for a related cross-country study that also features Austria, see Ivanova et al., 2017). Additionally, the literature so far tends to focus on one type of inequality, either consumption or income, neglecting potential dynamics between the two.

Apart from income as an important driver of unequal household environmental impacts, previous literature highlights the role of urbanization (Sato, 2014; Li and Lin, 2015; Ottelin et al., 2019;). For Austria, Muñoz et al. (2022) conclude that households in urban centres have the lowest carbon footprint, while semi-urban households have the highest carbon footprint on average. This finding is supported by evidence from a range of other high-income countries (Minx et al., 2013; Long et al., 2017; Ottelin et al., 2019).

In line with ongoing economic specialization and the growth of global trade, research stresses the importance of the carbon footprint of goods and services (also referred to as consumption-based GHG emissions) as an essential complement to territorial emissions accounting (Wiedmann, 2009; Davis and Caldeira, 2010; Steininger et al., 2018). Taking the carbon footprint into account is crucial since significant shares of consumption goods are produced in transnational, global production chains, especially in the case of small open economies such as Austria (Ivanova et al., 2016; Steininger et al., 2018). The carbon footprint perspective, compared to the territorial-based approach used in the United Nations Framework Convention on Climate Change, offers the advantage that it includes emissions from international trade and carbon leakage (Peters, 2008; Wiedmann, 2009; Davis and Caldeira, 2010).

The comparison of the carbon footprint with territorial emissions has generated important insights. Several studies have shown that almost all industrial or Annex B countries exhibit higher carbon footprints than territorial emissions, whereas non-Annex B and emerging economies feature the opposite pattern (Davis and Caldeira, 2010). Peters et al. (2011) show that these imbalances tend to be reinforced as global emissions resulting from international trade have been rising in particular in the period from 1990 to 2008. Since then, the gap between production-based emissions and the carbon footprint stabilized (Wood et al., 2020). While for most industrial countries the carbon footprint increased faster than territorial emissions, there is a rapid growth in territorial emissions in emerging countries, which are in fact being exported elsewhere (Sato, 2014). For Austria, previous research has shown that the carbon footprint exceeds territorial emissions by 40 to 50% (Muñoz and Steininger, 2010; Steininger et al., 2018). Two thirds of the CO_2e emissions of final demand occur elsewhere, mainly in Germany, the USA, Italy, the United Kingdom and Eastern Europe. This puts Austria among the top 10 countries where net imports constitute the most significant fraction of consumption emissions (Davis and Caldeira, 2010; Steininger et al., 2018).

3. Data

We use two data sets for our analysis of the distribution and structure

of household emissions. First, direct and indirect emissions are obtained from the multi-regional input-output database EXIOBASE3 (Version 3.3). This database maps the complex net of global economic relationships and their environmental repercussions for 44 countries and five RoW regions (Stadler et al., 2018). Each region comprises information on 163 industries and 200 products (Tukker et al., 2013; Tukker et al., 2014; Wood et al., 2014). The great detail on the product level and the possibility to explicitly account for different production technologies in various countries make EXIOBASE3 the most suitable database for our study. Since we focus on GHG emissions, the global warming potential (GWP) metric is used to express the greenhouse gases captured in the database (CO_2, methane, nitrous oxide and sulphur hexafluoride) in equivalent terms (CO_2e).

EXIOBASE3 arranges the information on GHG emissions in the *Classification of Individual Consumption by Purpose* (COICOP 1999). In this way, indirect household emission intensities are obtained on a COICOP three-digit level (115 product groups) in order to match household expenditure classifications.[1] The coefficients correspond to the emission of CO_2e per euro spent in specific product groups (in purchaser prices) and are provided in Appendix table A.1. In a second step, we aggregate emissions to six expense groups: food, housing, energy, mobility, goods, and services for the facilitation of analysis and visualization (Mackenzie et al., 2008). The allocation of individual consumption goods to the broader expense groups is primarily determined by the hierarchy of the COICOP classification (12 main groups) and further assigned manually to six remaining groups. Direct emissions, in contrast, are only available on a regional level in EXIOBASE3. To allocate direct emissions to the expense groups, we follow Ivanova et al. (2016) and distribute the CO_2e values between housing and mobility.[2]

The allocation of CO_2e emissions to households is based on the Austrian Household Budget Survey (HBS) of 2009/10, which is a representative expenditure survey provided by Statistics Austria (Statistik Austria, 2013). The survey covers a sample of 6,534 households with detailed information on consumption expenditure conforming with the COICOP classification. HBS data collection involves a combination of personal interviews and expenditure diaries which are maintained by the households for two weeks. The survey period is distributed throughout the year to account for seasonal fluctuations and holidays. Besides the expenditure information, the survey provides details on disposable household income and a variety of socio-economic characteristics. With HBS data, we are thus able not only to link aggregate consumption and emissions data, but also to analyse distributional aspects of GHG emissions.

Table 1 provides descriptive information on disposable income and consumption expenditure in the HBS. The mean annual household income estimated from the data is around €37,600 which is only slightly higher than annual average expenditure (€34,200). The table further shows mean expenditure on individual expense groups as well as deviations from the sample mean for various socio-demographic characteristics. Personal characteristics, like gender and education, are compiled about the household reference person, who is defined by the HBS as the household member who contributes the most to household income. With regard to educational levels, we find significant differences concerning expenditure on mobility, goods, and services and to a lesser degree for food and energy. Households with upper secondary education closely resemble the mean estimates, while higher educated households have greater expenses especially for goods and services.

Expenses for housing and mobility might depend on the provision of publicly funded infrastructure. Thus, a spatial perspective on the Austrian provinces might be of interest. Especially in the capital Vienna, the extensive provision of public housing and transport is reflected in dramatically lower household expenses in both categories (21% below average). This trend also applies to highly populated areas in general, where expenses for housing, mobility and energy are significantly below average (−12%, −18% and −20% respectively). Concerning the position in the income distribution, there are substantial disparities in consumption. The most significant spending gaps between high and low-income households arise for mobility, services and goods. For instance, while the top quintile spends nearly 180% of the overall average on mobility, the bottom quintile spends only 65%.

As expected, consumption increases with household size and mirrors the corresponding income differences with respect to household size. At the same time, larger households are able to benefit from economies of scale in terms of consumption, which ceteris paribus translates into lower emissions (Ivanova and Büchs, 2020; Wiedenhofer et al., 2018; Underwood and Zahran, 2015). To account for such household composition effects, we also calculate per capita values and alternatively apply OECD equivalence scales in this paper.

4. Methodology

Our methodological approach aims to focus on the carbon footprint of household consumption rather than just territorial-based emissions accounting. This strategy requires the assignment of global emissions embodied in the production and transport process to the final consumer goods (Wiedmann et al., 2006; Peters, 2008; Wiedmann, 2009; Minx et al., 2009). At the household level, the entire carbon footprint is the result of direct (d) and indirect (i) emissions,

$$GHG_{tot} = GHG_d + GHG_i$$

Direct household emissions, GHG_d, are associated with private transport and energy consumption in the form of fossil fuels. Direct emissions are thus linked to mobility (motor vehicles, etc.) and energy consumption (residential heating, cooking, etc.). Indirect emissions, GHG_i, are embodied in the production process of goods and services consumed by households. This includes the extraction of raw materials, the production of intermediate goods, the final production process and the transportation of goods. While the actual origin of these CO_2e emissions can be anywhere around the globe, we assign them to local consumption. In EXIOBASE3, we are able to distinguish between indirect emissions originating domestically (GHG_{iAT}), within the EU (GHG_{iEU}), and residual indirect emissions from the rest of world (GHG_{iRoW}).

Total emissions can be written as the product of the emission intensities per euro multiplied by the total expenditure for a given consumption category c,

$$GHG_{d,i^*} = e_{d,i^*} \times exp_{d,i^*} \quad (1)$$

where $e_{d,\ i^*}$ is a vector of (in-)direct emission intensities expressed in kilograms of CO_2e emissions per euro spent (kg CO_2e /€) and $exp_{d,\ i^*}$ is a matrix of household expenditure (in €) for each household and its associated spending pattern. As mentioned above, we obtain emission intensities by spending category from the EXIOBASE3 database, while household expenditure is taken from the Austrian HBS. When calculating household emissions by multiplying GHG emission intensities by the amount of euros spent in the various expenditure categories as shown in Eq. (1), we implicitly assume that the prices and quality of specific consumption goods are identical for all households. We assign emissions to the individual households exclusively depending on their level of expenditure.

[1] Indirect emissions on a COICOP three-digit level were kindly provided by Hanspeter Wieland (Institute for Ecological Economics, WU Vienna) from the EXIOBASE3 data base (Stadler et al., 2018).

[2] Ivanova et al. (2016), whose analysis is also based on the EXIOBASE3 database, divide direct emissions using the emission factors calculated by Lee (2008) and conclude that in Austria in 2011 around 74% of direct CO_2e emissions result from mobility (fuels and lubricants for personal transport equipment). The remaining 26% result from shelter (gas, solid and liquid fuels for heating).

Table 1
Expenditures and income by household characteristics.

	Obs.	Expenditure							Income		
		Total	Food	Housing	Energy	Mobility	Goods	Services	Household	Per capita	Equivalized
Overall											
Mean (in €)		34,224	5075	6031	1645	5218	11,833	4421	37,602	19,053	24,192
Gender											
Female	48%	−8%	−6%	−4%	−4%	−18%	−6%	−10%	−9%	−2%	−4%
Male	52%	7%	6%	4%	3%	17%	5%	9%	8%	2%	4%
Education											
Compulsory	20%	−28%	−5%	−19%	−5%	−38%	−38%	−35%	−23%	−23%	−24%
Upper secondary	63%	3%	2%	1%	0%	6%	3%	2%	1%	0%	1%
Post-secondary	6%	19%	9%	11%	14%	32%	19%	24%	15%	2%	7%
Tertiary	11%	24%	−5%	19%	−1%	17%	41%	34%	28%	37%	35%
Provinces											
Burgenland	3%	−4%	−3%	−12%	17%	2%	−9%	4%	1%	−2%	−1%
Carinthia	7%	7%	11%	0%	16%	5%	6%	15%	−9%	−15%	−13%
Lower Austria	18%	8%	5%	14%	16%	17%	3%	3%	10%	3%	6%
Salzburg	6%	6%	2%	15%	−2%	2%	4%	10%	3%	0%	2%
Styria	14%	−3%	−3%	−2%	12%	5%	−8%	−6%	−1%	−5%	−4%
Tyrol	8%	−1%	3%	8%	−4%	−14%	−1%	−3%	−5%	−4%	−4%
Upper Austria	16%	3%	6%	2%	2%	14%	−1%	2%	2%	−9%	−5%
Vienna	23%	−10%	−12%	−21%	−24%	−21%	2%	−6%	−6%	13%	6%
Vorarlberg	4%	4%	5%	26%	−11%	−14%	3%	−1%	4%	−2%	0%
Urbanization											
Highly populated	39%	−6%	−7%	−12%	−20%	−18%	3%	−2%	−4%	9%	4%
Medium populated	25%	8%	2%	10%	11%	16%	7%	8%	7%	3%	4%
Sparsly populated	36%	1%	6%	6%	14%	8%	−8%	−3%	0%	−11%	−8%
Household size											
1	36%	−34%	−40%	−26%	−28%	−45%	−34%	−32%	−36%	26%	−1%
2	29%	3%	0%	5%	4%	4%	4%	0%	6%	4%	10%
3	16%	24%	24%	19%	17%	30%	24%	23%	22%	−19%	−1%
4	13%	37%	42%	28%	27%	52%	34%	39%	36%	−33%	−7%
5+	7%	42%	75%	21%	37%	48%	38%	37%	44%	−47%	−23%
Income quintile											
1	19%	−50%	−36%	−42%	−32%	−65%	−53%	−57%	−60%	−31%	−43%
2	21%	−24%	−19%	−20%	−17%	−30%	−27%	−24%	−35%	−6%	−18%
3	20%	−4%	−1%	1%	4%	−11%	−6%	−8%	−11%	−1%	−4%
4	20%	19%	15%	20%	15%	25%	18%	17%	20%	4%	12%
5	20%	58%	39%	39%	29%	79%	68%	70%	85%	33%	52%

Notes: This table shows the structure of household consumption expenditure and household disposable income stratified by various household characteristics. Observations are given as percentage shares of the total household population. Expenditure and income are presented as a percentage deviation from the sample mean in the first row. *Source:* HBS 2009/10, own calculations.

After linking emissions to household consumption, we are able to include the dimension of income distribution into the analysis. The HBS provides annual disposable household income which we use to assign households to income deciles. To account for differing household structure, some papers use per capita figures or deflate expenditures and the carbon footprint using OECD equivalence scales (Isaksen and Narbel, 2017; Chitnis et al., 2014). The latter approach assigns a value of 1 to the household head, 0.5 to each additional household member over the age of 14 and 0.3 to each child. Household totals for income, consumption, and emissions are then divided by the sum of these weights to take differences in household composition into account. However, the application of income equivalence scales to other variables like consumption or emissions might be controversial and the choice of a specific scale affects the results. We thus focus on the analysis at the household level and present results for the OECD equivalence and per capita approaches in the Appendix.

Linking EXIOBASE3 and HBS further enables us to incorporate various socio-demographic characteristics into the analysis. In an econometric exercise, we study household attributes that are associated with the level of emissions and a potential tax burden, assuming a CO_2e price of €100 per metric ton. We estimate linear probability models with three dependent variables, which are annual household CO_2e emissions and indicators whether a household is among the highest 10% or 33% of tax-to-income ratios, and a set of socio-demographic explanatory variables.

5. Results

This paper provides empirical evidence on three questions. First, we investigate the relationship between the distribution of household income and the carbon footprint. Second, we analyse the origin of emissions across the income distribution, which is a relevant question for the design of CO_2e taxation. Third, we identify households which might be particularly exposed to CO_2e taxation or policies affecting prices of carbon-intensive goods and services. While many papers opt for one concept of income distribution, we show results for three different income concepts. This section is based on the household income distribution; however, we rerun all calculations with the distribution of per capita income and equivalized household income. We present the respective figures in the Appendix, sections B and C, and point to differences where necessary.

5.1. Emissions by income distribution

Inequality in incomes is typically higher than in expenditure, which is in turn higher than emissions inequality. Fig. 1 shows the distribution of income, expenditure and emissions with respect to the deciles of disposable household income. The top decile of the income distribution receives 22% of income, spends 18% of expenditures, and causes 17% of emissions. This observation corresponds to the expectation of a decreasing marginal propensity to consume along income deciles. The bottom decile of income distribution, in contrast, accounts for just 3% of income, 4% of expenditure and 4% of emissions. The top income decile is thus responsible for roughly 4.1 times more emissions than the bottom decile. The bottom half of the income distribution in Austria emits 34% of total emissions and the top half around 66%.

Fig. 2 illustrates household expenditure in thousands of euros and CO_2e emissions in metric tons with respect to the income deciles of the disposable household income distribution. As described in the data section, we divide annual consumption into six expenditure groups: food, housing, energy, mobility, goods, and services. The left panel shows that expenditure on goods and services significantly increases with income, while expenses for food and energy show only a moderate increase across the income distribution. This observation corresponds to Engel's law, stating that the percentage of income allocated for food purchases decreases as income rises. In contrast, household expenditure on housing and mobility rises quite synchronously with increasing income. The expenses for food and energy in the top decile amount to more than twice the corresponding value of the bottom decile, for housing and mobility the ratio is approximately three and for goods and services the ratio is more than four times.

The right panel of Fig. 2 presents the average CO_2e emissions per income decile for the six expense groups. Emissions originating from mobility are the highest across the whole distribution, as the multiplier for direct CO_2e emissions is by far the largest in this category. The top decile emits three times more CO_2e for mobility than the bottom decile. The second most important category is energy for the bottom nine deciles and consumer goods for the top decile of the income distribution. The ratio of emissions in the bottom and top income decile amounts to three for energy and four for consumer goods. In total, the lowest decile in the distribution of household income emits roughly ten metric tons of CO_2e on average, whereas the top decile emits almost 40 tons of CO_2e.

Fig. 3 shows the relative shares of the consumption and emission categories across the household income distribution. As already indicated by the large differences in the absolute expenses between income deciles, these trends are visible in the relative structure across the income distribution. In line with Engel's law, the relative importance of food declines from roughly 20% of total expenditure in the bottom decile to 10% in the top decile. In contrast, the consumption of goods and services becomes increasingly significant. Together, these two groups account for more than half of total consumption in the top income decile. The other expense groups like housing (17%), energy (4–5%) and mobility (14–15%) remain fairly stable across the distribution.

The composition of CO_2e emissions, as depicted in the right panel of Fig. 3, changes only marginally across the distribution. Only emissions from the consumption of goods shows increasing relevance, while emissions from food expenditure decline slightly in relative terms. As already indicated by the absolute emissions, the shares of mobility (26 to 38%) and energy (18 to 30%) exceed the relative importance of the corresponding expenditure levels by far. The strong weight of emissions in these two categories reflects the high CO_2e multipliers for mobility and energy.

5.2. Emissions by regional origin

Fig. 4 shows the origin of emissions and distinguishes between domestic and external origin, which is relevant for different types of CO_2e taxation. We take advantage of the geographic information in the EXIOBASE3 dataset and assign external indirect emissions to EU member countries and to RoW. Interestingly, the geographic composition of emissions remains surprisingly stable across the household income distribution. The results suggest that roughly 55% of all emissions are accrued in Austria, with direct and indirect emissions each accounting for half of the domestic CO_2e released. Around 20% of total emissions are assigned to other EU countries and approximately 25% originate from RoW countries. This picture does not change significantly for the distribution of equivalized (Fig. B.3) and per capita household income (Fig. C.3).

From a policy perspective, these results suggest that implementing measures which only address direct domestic emissions in Austria ignores almost three quarters of all emissions. A national carbon tax, for instance on fossil fuels and energy, would thus only cover a quarter of total emissions caused by domestic consumption. A carbon border tax would affect another quarter of total emissions, while the EU ETS concerns roughly half of all emissions (indirect emissions in Austria and other EU countries). These figures underpin the need for policymakers to tackle CO_2e emissions of different regional origin in order to develop comprehensive and effective measures against the climate crisis. It is key to look at the carbon footprint, which captures all GHG emissions in the global production process and in international trade. The stable shares of emission origins, however, indicate that different policies would have similar relative effects across the income distribution.

5.3. Overburdened households

While there is a clear positive relationship between income and carbon footprint, the remaining variation in CO_2e emissions within groups of households with similar levels of income is substantial. Households within the same income band are thus exposed to a markedly different extent to consumption-based CO_2e taxes.

Table 2 shows the proportion of the variance in GHG emissions explained by income as measured by the R^2 of simple OLS regressions. It is shown for the total carbon footprint as well as its four components: direct domestic emissions, indirect domestic emissions, indirect emissions that originate in the European Union, and indirect emissions from RoW. In the household perspective, less than one third of the observed dispersion in the carbon footprint can be explained by variation in household income. This means that more than two thirds of the variation is driven by other factors and characteristics. Even more striking is the reduction in the R^2 statistic in the case of direct domestic emissions where income accounts for only 16% of the variation in the data. The respective figures for indirect emissions are 24% (domestic), 29% (EU) and 28% (RoW). A similar exercise conducted for the per capita and equivalized income distribution reveals qualitatively the same patterns, albeit at an even lower level of explained variance. As income seems to be an important but clearly not the only driver of carbon emissions in private households, the question arises how a carbon tax would affect the financial situation not only at the sample average, but at different income levels.

Some households might even be overburdened by the rising prices of carbon-intensive goods with respect to their income. In a static exercise, we introduce a comprehensive carbon tax and identify those observations with the highest tax-to-income ratio as potentially overburdened households. The literature and policy debate regularly calls for a CO_2e price in the range of €70–140 per metric ton by 2030 (Intergovernmental Panel on Climate Change (IPCC), 2014). Some experts argue that this price is the lower bound to unfold steering effects that are needed to reduce CO_2e emissions substantially (Mattauch et al., 2020; Stern and Stiglitz, 2021). We consider a global CO_2e price of €100 irrespective of the origin of emissions that is fully passed through to consumers, and apply this tax to the carbon-related expenditure of all households. Consequently, we calculate a potential tax burden and its relation to household income in order to identify households with relatively high

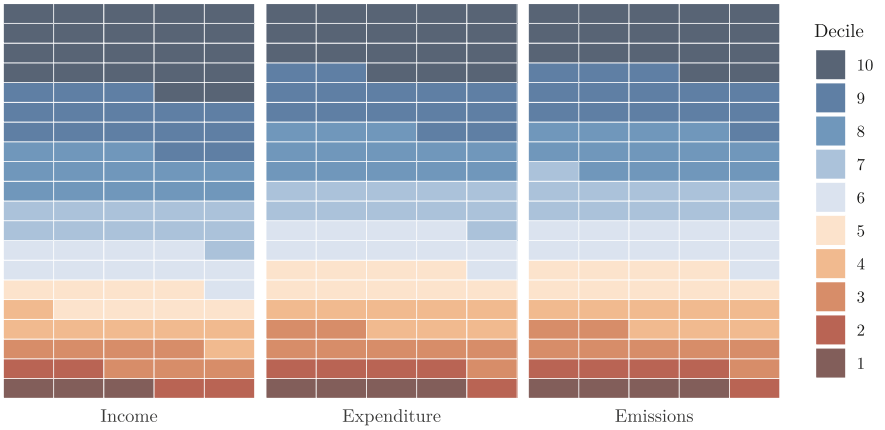

Fig. 1. Shares of income, expenditure and emissions by income deciles.
Notes: This graph shows the distribution of disposable income, consumption expenditure, and CO_2e emissions over deciles of disposable household income. Each square represents 1% of the respective variable. For instance, the top income decile receives 22% of total income, generates 18% of expenditures, and emits 17% of emissions.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

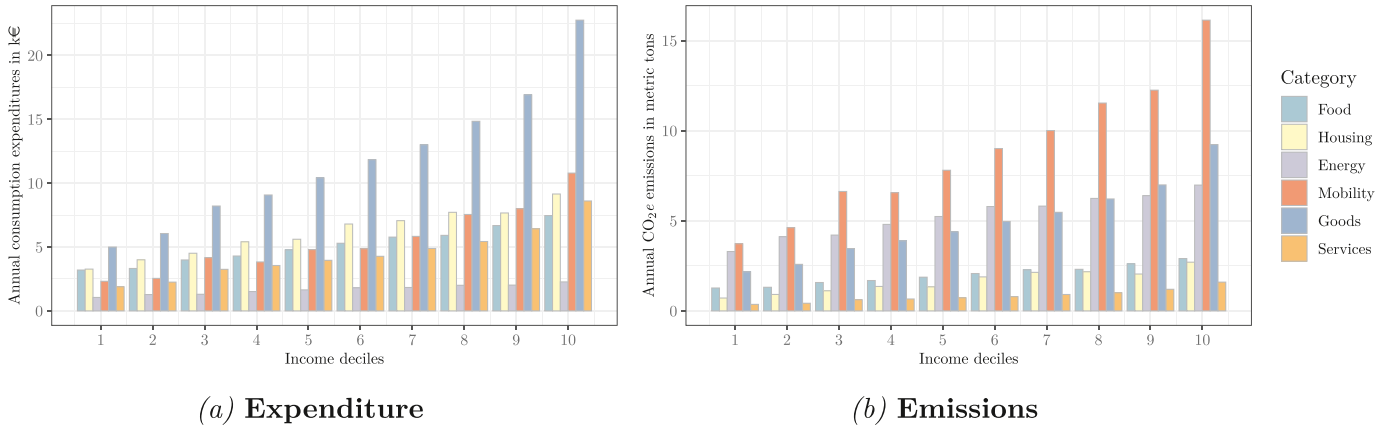

Fig. 2. Annual expenditure and CO_2e emissions by consumption category across the household income distribution.
Notes: These graphs show the equivalized annual consumption expenditure on food, housing, energy, mobility, goods, and services over deciles of disposable household income. Housing, mobility, goods, and services significantly increase across the distribution, whereas expenditure on food and energy is comparatively inelastic with respect to income.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

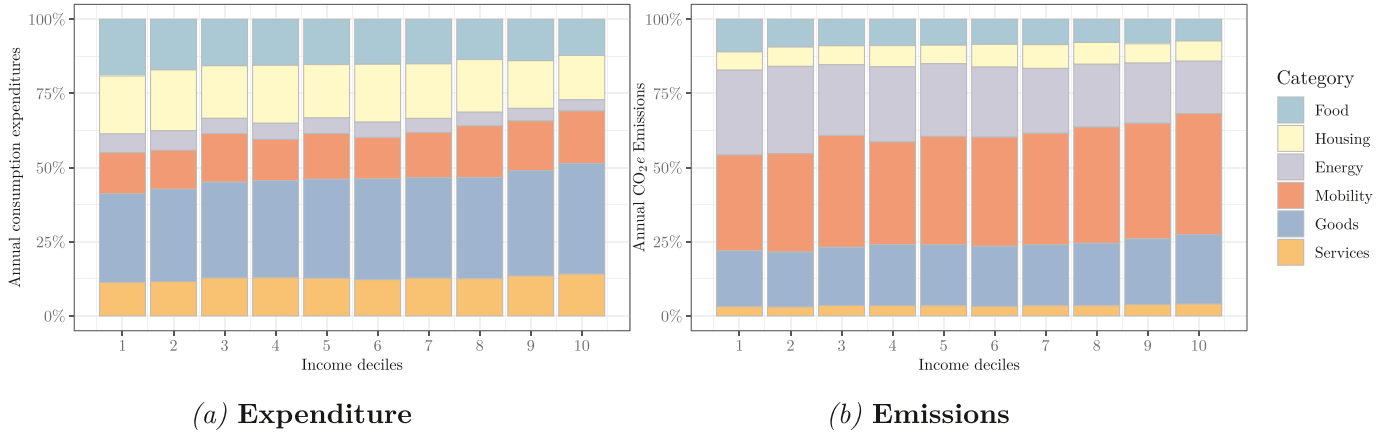

Fig. 3. Structure of expenditure and CO_2e emissions by consumption category across the household income distribution.
Notes: These graphs show the proportional composition of consumption expenditure and CO_2e emissions for six consumption categories over deciles of disposable household income. The relative importance of CO_2e emissions caused by energy and mobility exceed their expenditure shares significantly, whereas housing and services have a disproportionally low impact on overall CO_2e emissions.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

tax-to-income ratios. Finally, we test the relationship between a series of socio-demographic variables and the chance of being overburdened by taxation.

The left panel of Fig. 5 illustrates the variation of CO_2e emissions within deciles of household income with box plots indicating the 25th, 50th, and 75th percentile. While median emissions increase with

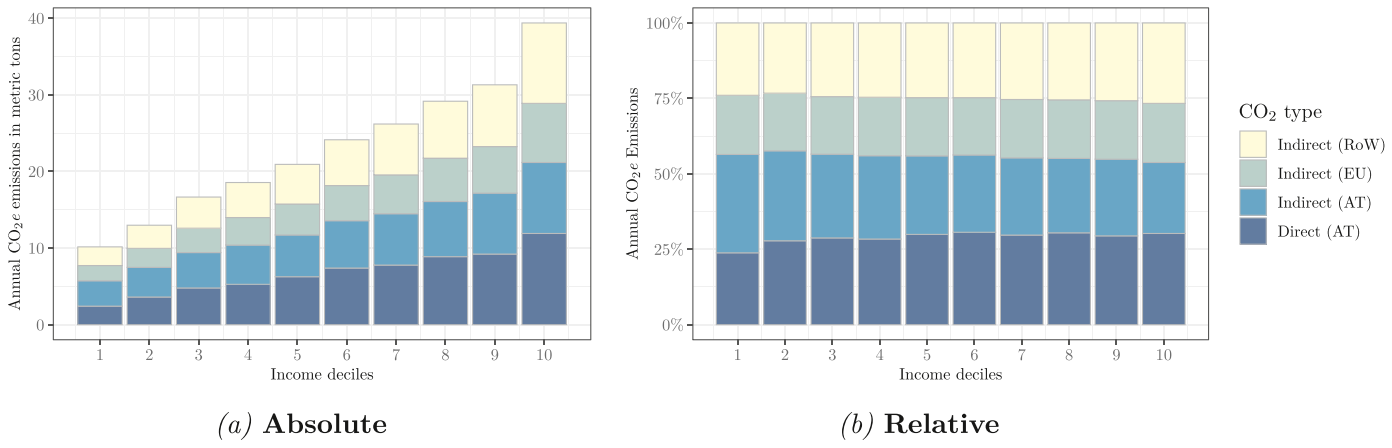

Fig. 4. Composition of CO_2e emissions by origin across the household income distribution.
Notes: These graphs show the origin of CO_2e emissions over deciles of disposable household income. Roughly 55% of emissions are accrued in Austria, 20% in other EU countries, and 25% in the rest of the world.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

Table 2
Variation in emissions explained by income in %.

	Carbon footprint	Direct AT	Indirect AT	Indirect EU	Indirect RoW
Households	31	16	24	29	28
Per capita	29	12	29	27	24
Equivalized	18	7	16	17	17

income, the box plots show a large dispersion of emissions within each income decile. Some households at the bottom of income distribution even emit as much as some households at the top. These households might be particularly affected by CO_2e taxation. The right panel of Fig. 5 shows the share of households that are among the top 10% or 33% with the highest tax-to-income ratios. The tax-to-income ratio is higher than 7.2% for the top 33% and higher than 11.2% for the top 10%. The average tax-to-income ratio across deciles ranges between 9.2% in the bottom and 4.9% in the top income decile. The figure shows that there are households in each decile that could be rated as overburdened; however, their number decreases strongly in the higher deciles. Many of these observations could also be labelled *excessive emitters* as they emit considerably more CO_2e than their peers in the income distribution. The figure shows that while many of the households in the bottom decile emit considerably less than the median household in the top decile, these households would be particularly affected by taxation as a proportion of their income. We are interested in the factors that explain why some households emit substantially more than others with similar income resources and eventually might be disproportionately exposed to carbon mitigation policies that increase CO_2e prices.

To answer this question, we employ regressions for different dependent variables, which are CO_2e emissions in tons and indicators whether a household belongs to the top third or decile in terms of tax-to-income ratios. We conduct regressions for both direct emissions and the carbon footprint with a set of socio-demographic variables provided by

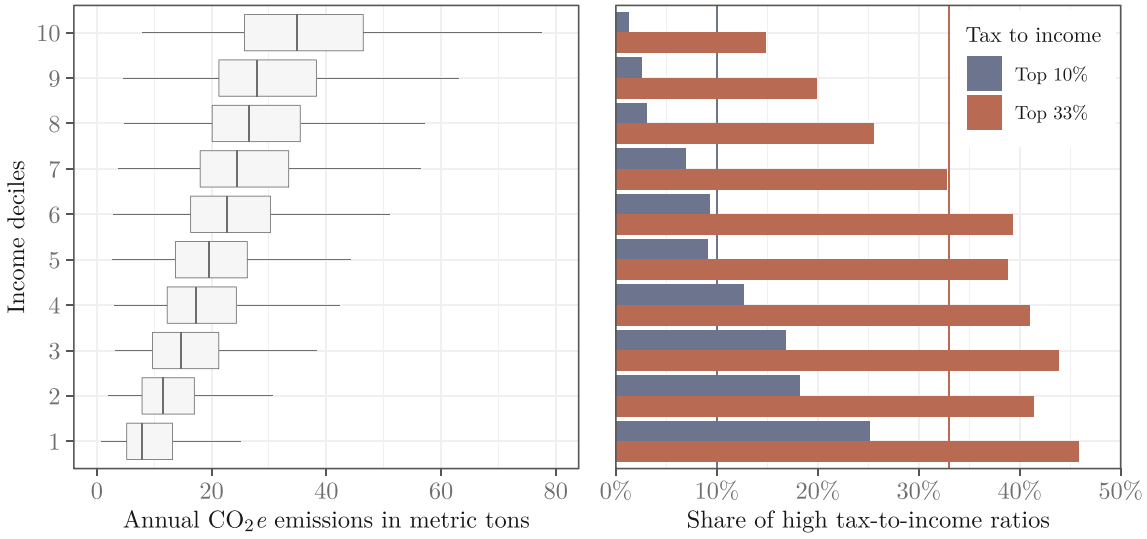

Fig. 5. Dispersion of annual CO_2e emissions and share of high tax-to-income ratios across the distribution of disposable household income.
Notes: The left panel of this graph shows the distribution of CO_2e emissions over deciles of disposable household income. The box plots depict the 25th, 50th, and 75th percentile of CO_2e emissions for each income decile. Supposing a price of €100 per ton of CO_2e, the right panel shows the share of observations that belong to the top 33% and 10% of tax-to-income ratios in the total sample. Households at the bottom of income distribution are disproportionally often affected by high tax-to-income ratios.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

the HBS. The first group of explanatory variables comprises the age, gender and education of the household reference person. We further add household information like the household size (number of adults and children) and the number of cars. As residential energy is known to be a substantial source of CO_2e emissions, we include a set of variables concerning the heating type (i.e. the energy source for heating such as coal, oil, gas, wood, district heating, or renewables like terrestrial heat or solar energy), the floor area in square meters, the year of construction and the dwelling type (whether the household lives in an apartment block, semi-, or detached housing). Since CO_2e emissions originating from mobility account for the largest share in total household emissions across the distribution, the region where households live and work might play a major role. While larger cities tend to provide widespread public transport networks, commuters on the countryside more often depend on their own motorized vehicles. We thus include the degree of urbanization (according to the tree–level Eurostat classification) as a proxy for the availability of public transport. Finally, we add a set of variables that account for the financial ease of adjusting to carbon-mitigating measures in order to reduce the tax burden, like a costly conversion of the heating system or switching to electromobility. These variables include household income, the ownership of real estate, housing savings plan,[3] and shares. Descriptive statistics for all explanatory variables can be found in Table D.1 in the Appendix.

Table 3 presents the results from the linear models for direct emissions and the carbon footprint. Among the large set of variables, we focus on a few distinct links in the data. The number of cars is not only associated with direct and total emissions, but substantially correlates with belonging to the potentially overburdened households. There is a significant difference between owning one or multiple cars, as the coefficients massively increase. The heating system is the second most important factor linked to emissions and the exposure to high tax-to-income ratios. While coal, oil and gas show a positive relationship with being overburdened, heating with renewables naturally decreases direct emissions and the potential tax-to-income burden. Surprisingly, households with district heating feature a larger carbon footprint and a higher probability of high tax-to-income ratio. Observations in highly populated residential areas are, as expected, linked to lower emissions and a lower likelihood of overburden. The dwelling type makes a difference as detached and semi-detached houses are associated with higher emissions and a higher risk of being overburdened as compared to apartment blocks. Another effect is found for the year of the building's construction, with older buildings seeming to be more energy-intensive. Households with older reference persons tend to emit less and are less likely to belong to the overburdened households. This is true for both direct and total emissions. The larger a household, the higher the emissions and the probability of ranking among overburdened households mainly with respect to the carbon footprint, but surprisingly not for direct emissions.

Overall, we find the highest increase in the probability of being potentially overburdened for households that own multiple cars or use coal or oil for heating. These results are stable for direct emissions and the carbon footprint, with the exception that gas heating becomes more relevant when looking at the carbon footprint. Our findings with respect to population density are in line with papers showing that living in suburban and rural areas is significantly more energy-intensive than living in urban centres (Lenzen et al., 2006; Shammin et al., 2010; Gill and Moeller, 2018). The literature points to "urban economies of scale" with regard to housing and mobility.

Many of these factors are common targets of carbon mitigation policies in order to create incentives for private households, such as thermal renovation, switching to public transport or replacing fossil fuel-based heating systems. From a distributional perspective, however this might generate adverse effects as the costs of individual measures differ considerably. While the number of cars in a household can be reduced rather quickly, replacing heating systems entails considerable investment costs. Households at the bottom of the income distribution may thus be locked-in in the short term with only minimal possibilities to avoid carbon taxation. Generating incentives to reduce emissions via the introduction of general CO_2e taxes should thus consider "sticky" household characteristics and include elements of social balance.

Evidence from Table 3 shows that it is households with lower incomes, no savings and no shares that are more likely to be in the overburdened group and might thus have liquidity constraints. This is even more apparent in the case of taxing direct domestic emissions, which will very likely be implemented first. While the estimated coefficient for disposable household income (measured in €1000) is positive and significant in the GHG regressions (i.e. columns (1) and (4) in Table 3), the relationship turns negative in terms of belonging to the top third or the top decile of households in terms of tax-to-income ratios. These results imply that households with larger incomes generate on average more emissions, however as the income elasticity of GHG emissions is below unity their budgets are less affected by carbon taxation measures.

For example, while an increase of household income by one unit (€1000) leads to an increase of direct emissions by 50 kg CO_2e and an expansion of the carbon footprint by 190 kg CO_2e, an income coefficient of −0.006 in column (2) implies that ceteris paribus the increase of income at the same time reduces the probability of belonging to the top third of households in terms of tax-to-income ratios by 0.6%. This carries both statistical and economic significance. As the income difference between the 2nd and the 8th decile amounts to roughly €40,000, our results suggest that the probability of belonging to the group of severely stressed households is 25–30% lower for households in the 8th decile compared to their counterparts in the 2nd decile. This pattern also clearly emerges in an alternative specification of the regressions that includes income decile dummies instead of the continuous income variable (see Table D.2 in the Appendix). Starting from the 3rd decile, the risk of belonging to the top 33% (or the top 10% respectively) of households in terms of tax-to-income ratios is statistically significant and monotonically declines. Looking at direct emissions, the probability of the upmost decile is reduced by half, in case of the carbon footprint regressions the coefficients points to a reduction of 80%.

6. Limitations

Our approach carries certain limitations. The analysis relies on a financial approach, where indirect and direct GHG emissions are transformed into a vector of emission intensities in order to match household expenditure data. Using these emission intensities per euro spent on a product group, we assume that CO_2e emissions are homogeneous for all products within a specific group. In other words, all households encounter the same quality and prices of goods and services even though alternative products might differ with respect to environmental sustainability. This limitation affects our results in two ways: on the one hand, as we cannot account for quality differences within product groups, emissions for households buying the eco-friendly high-quality alternative may be overestimated. There is literature that emissions for richer households are overestimated as they tend to buy higher-quality wares (Girod and De Haan, 2010). On the other hand, the emissions of poor households may be overestimated if they face higher prices for the same product group and thus seem to be buying relatively more. This argument corresponds to evidence of a "poverty penalty" in retail (Mendoza, 2011; Talukdar, 2008). For instance, we are able to distinguish household energy consumption between the COICOP categories electricity, gas, liquid fuels, solid fuels, heating energy, and other heating costs, but not between natural gas and biogas.

More general limitations arise from the available data sets. The

[3] A *Bausparvertrag* is a tax-free savings account which entitles the account holder to a housing loan at a certain interest rate. It is however also frequently used as a savings account and is thus similar to an ISA in the UK, which also allows for tax-free interest payments.

Table 3
Estimation of socio-demographic factors for CO_2e emissions and tax-to-income ratio.

	Direct emissions			Carbon footprint		
	GHG	Tax/income		GHG	Tax/income	
	t CO_2e	Top 33%	Top 10%	t CO_2e	Top 33%	Top 10%
	(1)	(2)	(3)	(4)	(5)	(6)
Age (ref: 31-45 yrs)						
30y and below	−0.102 (0.260)	0.019 (0.023)	−0.002 (0.016)	−0.325 (0.543)	0.014 (0.024)	0.004 (0.017)
45-60y	−0.191 (0.237)	−0.008 (0.019)	−0.011 (0.013)	0.610 (0.493)	0.040 (0.019)*	−0.002 (0.013)
61-75y	−0.908 (0.260)***	−0.054 (0.022)*	−0.040 (0.015)**	−0.754 (0.570)	−0.009 (0.023)	−0.021 (0.016)
76y and above	−1.835 (0.299)***	−0.126 (0.027)***	−0.075 (0.018)***	−3.229 (0.642)***	−0.117 (0.028)***	−0.073 (0.018)***
Gender (ref: female)						
Male	0.382 (0.163)*	0.039 (0.013)**	0.008 (0.009)	0.407 (0.351)	0.008 (0.014)	0.009 (0.009)
Education (ref: upper secondary)						
Compulsory	−0.434 (0.195)*	−0.035 (0.018)*	−0.018 (0.012)	−1.727 (0.431)***	−0.029 (0.019)	−0.022 (0.013)$^{+}$
Post-secondary	−0.139 (0.308)	−0.020 (0.027)	−0.009 (0.017)	−0.139 (0.689)	−0.019 (0.027)	−0.008 (0.017)
Tertiary	−0.002 (0.278)	−0.002 (0.022)	0.011 (0.014)	0.564 (0.573)	0.007 (0.024)	0.003 (0.014)
Number of adults (ref: 1)						
2	−0.135 (0.180)	−0.017 (0.019)	−0.030 (0.013)*	1.042 (0.407)*	−0.013 (0.022)	−0.018 (0.015)
3	0.943 (0.383)*	0.025 (0.030)	0.010 (0.022)	3.521 (0.834)***	0.001 (0.034)	0.037 (0.024)
4+	1.718 (0.536)**	0.049 (0.044)	0.033 (0.029)	5.168 (1.182)***	0.098 (0.050)*	0.061 (0.034)$^{+}$
Number of children (ref: 0)						
1	0.458 (0.303)	0.008 (0.021)	0.003 (0.014)	1.810 (0.625)**	0.032 (0.021)	−0.009 (0.013)
2	0.351 (0.302)	0.020 (0.024)	0.005 (0.016)	1.822 (0.622)**	0.051 (0.024)*	−0.007 (0.015)
3	−0.319 (0.514)	−0.079 (0.036)*	−0.035 (0.024)	2.514 (1.066)*	0.015 (0.038)	−0.008 (0.026)
4+	0.224 (1.315)	0.008 (0.069)	0.044 (0.058)	1.298 (2.497)	0.055 (0.066)	0.019 (0.044)
Number of cars owned (ref: 0)						
1	3.356 (0.159)***	0.305 (0.016)***	0.131 (0.011)***	6.045 (0.367)***	0.227 (0.018)***	0.094 (0.013)***
2	5.907 (0.290)***	0.429 (0.024)***	0.191 (0.016)***	11.019 (0.626)***	0.324 (0.025)***	0.145 (0.018)***
Floor area						
Square meters	0.006 (0.002)*	0.000 (0.000)	0.000 (0.000)	0.033 (0.006)***	0.001 (0.000)***	0.000 (0.000)*
Dwelling type (ref: apartment block)						
Double-family home	0.694 (0.273)*	0.056 (0.024)*	0.020 (0.017)	0.951 (0.645)	0.039 (0.024)	−0.001 (0.015)
Single-family home	0.885 (0.278)**	0.054 (0.022)*	0.011 (0.016)	0.686 (0.638)	0.017 (0.023)	−0.003 (0.015)
Year of construction (ref: 1970–1999)						
1945 to 1970	0.382 (0.188)*	0.042 (0.016)*	0.018 (0.011)$^{+}$	0.413 (0.407)	0.022 (0.017)	0.018 (0.012)
2000 to 2010	−0.210 (0.338)	−0.016 (0.022)	0.004 (0.015)	0.369 (0.706)	0.008 (0.024)	0.023 (0.016)
Prior 1945	0.172 (0.203)	0.022 (0.017)	0.023 (0.012)$^{+}$	0.072 (0.445)	0.012 (0.018)	0.015 (0.012)
Heating system						
Coal	1.132 (0.454)*	0.170 (0.044)***	0.080 (0.036)*	0.816 (0.918)	0.073 (0.045)	0.094 (0.034)**
District heating	−0.551 (0.328)$^{+}$	−0.029 (0.029)	−0.021 (0.018)	3.231 (0.618)***	0.115 (0.029)***	0.057 (0.017)***
Gas	1.511 (0.308)***	0.085 (0.029)**	0.032 (0.018)$^{+}$	3.279 (0.584)***	0.099 (0.028)***	0.054 (0.015)***
Heating oil	2.126 (0.360)***	0.135 (0.032)***	0.060 (0.021)**	3.266 (0.677)***	0.120 (0.031)***	0.062 (0.017)***
Other	−0.797 (0.413)$^{+}$	−0.072 (0.040)$^{+}$	−0.044 (0.024)$^{+}$	−1.530 (0.794)$^{+}$	−0.013 (0.041)	−0.037 (0.017)*
Renewables	−1.774 (0.621)**	−0.126 (0.044)**	−0.015 (0.028)	−1.973 (1.235)	−0.040 (0.046)	0.013 (0.027)
Wood, Pellets	0.045 (0.380)	−0.004 (0.032)	0.016 (0.021)	−0.947 (0.734)	0.004 (0.032)	0.019 (0.018)
Urbanization (ref: medium populated)						
Highly populated	−1.115 (0.232)***	−0.092 (0.019)***	−0.014 (0.012)	−1.646 (0.524)**	−0.076 (0.020)***	−0.002 (0.012)
Sparsly populated	0.098 (0.208)	0.002 (0.017)	0.029 (0.012)*	−0.524 (0.444)	0.004 (0.018)	0.005 (0.012)
Proxies for the capacity to adjust						
Disposable HH income (k€)	0.048 (0.006)***	−0.006 (0.001)***	−0.004 (0.001)***	0.187 (0.017)***	−0.008 (0.001)***	−0.005 (0.001)***
Owns main residence	−0.151 (0.203)	0.002 (0.018)	−0.008 (0.012)	0.857 (0.462)$^{+}$	0.008 (0.019)	0.010 (0.012)
Has a 2^{nd} residence	0.684 (0.379)$^{+}$	0.059 (0.029)*	0.012 (0.016)	2.543 (0.867)**	0.058 (0.028)*	0.001 (0.016)
Has housing savings plan	−0.224 (0.166)	−0.008 (0.014)	−0.017 (0.010)	0.245 (0.357)	0.003 (0.016)	−0.006 (0.010)
Has shares	−0.358 (0.205)$^{+}$	−0.019 (0.016)	−0.022 (0.010)*	0.460 (0.457)	0.004 (0.017)	0.002 (0.011)
Num.Obs.	6533	6533	6533	6533	6533	6533
R^2	0.370	0.193	0.101	0.461	0.149	0.091
Adj. R^2	0.367	0.188	0.096	0.458	0.144	0.085

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{+}p < 0.1$.

Notes: This table shows heteroscedasticity-consistent (White's HC3 estimator) OLS regression models for direct emissions and the carbon footprint with socio-demographic household characteristics. The dependent variable in columns (1) and (4) is annual household CO_2e emissions in metric tons (see section 4), and in the linear probability models presented in columns (2), (3), (5), and (6) an indicator whether a household belongs to the top 10% or 33% of tax-to-income ratios.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

accuracy of both EXIOBASE3 and the Household Budget Survey is limited by imprecise information and carries certain shortcomings. Environmentally extended input-output models rely on a number of different sources (national account systems, data on energy use, and emissions from all over the world) which might lead to inaccuracies. Past studies comparing different approaches and databases show relatively good agreement in terms of sector-specific and overall GHG emissions (Moran and Wood, 2014; Owen et al., 2014; Eisenmenger et al., 2016). We cannot rule out that other emission data would result in differing outcomes. However, EXIOBASE3 seems to be the most comprehensive global multiregional input-output database available with a high level of sector disaggregation which captures the heterogeneous nature of economic sectors in terms of their environmental characteristics (Steen-Olsen et al., 2014; Owen et al., 2014; Tukker et al., 2018).

Expenditure surveys rely on the accuracy of the time-intense exercise of completing household purchase diaries. Several factors have been identified as sources of mismatch between survey and national accounts aggregates, such as recall bias, faulty sampling, and poor supervision (Min and Rao, 2018). Among these are also the unwillingness to report on sensitive issues like alcohol, drugs, sweets and pharmaceuticals (Steen-Olsen et al., 2016). For instance, the difference between national accounts and survey totals for the consumption of alcohol and tobacco is roughly one third in Austria. In addition, there is undercoverage of specific groups in the survey sample, such as non-German-speaking persons, working single parents, and households at both ends of income distribution (Statistik Austria, 2013). In Austria, the survey aggregate over all products and services is 13% below the national accounts, which is at least partly due to conceptual differences between the data sources (Kronsteiner-Mann and Schachl, 2011). Another shortcoming of the HBS is the income definition and the lack of wealth-related variables. HBS typically does not cover assets, savings, gifts, or supplementary payments, which may be used to finance consumption expenditures. This might result in an upward bias of the tax-to-income ratios since the denominator only fuels part of a household's financial resources. To address this issue we control for a number of proxies—such as age, which correlates with savings—to partially capture such effects.

Given the limitations in both data sets, we have to further assume fixed consumption shares of domestic and imported goods across households. This could affect our results if the consumption of more (or less) carbon intensive domestic (or imported) products is systematically related to household income.

7. Conclusion

This paper adds the case of Austria to the existing literature on the nexus between income distribution and the carbon footprint. Combining the Household Budget Survey with EXIOBASE3 emissions data provides novel insights into the social dimension of GHG (CO_2e) emissions. We are able to provide empirical evidence on (1) the relationship between income distribution and the carbon footprint, (2) the origin of emissions across the income distribution, and (3) factors that contribute to the likelihood of being particularly exposed to increasing CO_2e prices by carbon mitigation policies.

With respect to the first question, our findings are in line with previous research for other countries, especially the UK (Büchs and Schnepf, 2013) or the Netherlands (Kerkhof et al., 2009b) but differ for others that have, e.g., a greener energy mix that translates into lower housing-related emissions (Isaksen and Narbel, 2017). We further show that emissions closely follow the increase in aggregate expenditures along the income scale. These are mainly driven by expenditure on mobility rather than the quantitatively more important expenditure on goods. Energy consumption is another large contributor to aggregate CO_2e emissions that steadily increases with income. In total, the top income decile is responsible for 17% of total emissions and emits 4.1 times more than the bottom income decile.

Regarding the regional origin of emissions, we find that direct, indirect local, EU-based, and rest-of-world emissions contribute approximately equal shares along the income distribution. For instance, a national CO_2e tax would affect all deciles roughly equally in relative terms; however, it would only cover some 25% of all emissions. A carbon border tax would affect another 25% of emissions, while the EU ETS on indirect Austrian and EU-based emissions would cover roughly half of emissions.

Finally, we introduce a CO_2e price of €100 per metric ton and identify households that would be affected by high tax-to-income ratios. These households might be particularly exposed to policies that increase the prices of carbon-intensive goods. We find that these households exhibit distinct characteristics, such as the ownership of multiple cars, fossil fuel-based heating technologies or detached houses, which is a finding that strongly supports existing evidence, e.g., for Ireland (Farrell, 2017). Importantly, also the income variable turns out to be negative, implying a regressive effect of carbon taxation in Austria, insofar as tax-to-income ratios decrease with higher income. This finding is very much in line with other studies, especially for high-income countries (for an extensive comparison, see Köppl and Schratzenstaller, 2021).

Putting these three arguments into perspective, we conclude first that carbon taxation needs to be universal, as isolated measures such as a local (country-wide) tax only captures a fraction of consumption-induced emissions, e.g. only 25% in Austria. Second, carbon taxation might lead to socially adverse effects, where households with unusually high emission profiles at the bottom of income distribution are adversely affected. A socially balanced approach would thus need to focus on the adaptability of these emitters to cleaner alternatives. This could be longer replacement periods for long-lasting goods such as quality housing, heating systems or additional financial incentives that allow for a faster transition process, such as renovation premiums or subsidies for exchanging oil-based heating systems. Furthermore, it might be worth considering whether linking a CO_2 or carbon footprint tax to household income might be feasible. In addition, regulatory measures could prevent companies from fully passing through carbon taxes to consumers. Related to this last issue it also becomes clear that price-based policy measures need to be embedded into a larger framework that enforces carbon reduction throughout the whole economy. Such other factors encompass, e.g., provisioning of public transportation alternatives or efficiency increases through thermal insulation of buildings that complement carbon taxation measures.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Appendix

Table A.1
CO_2e Emission multipliers.

	Direct	Indirect		
	AT	AT	EU	World
Food				
Bread and cereals	0.00	0.12	0.16	0.13
Meat	0.00	0.15	0.11	0.09
Fish and seafood	0.00	0.21	0.20	0.12
Milk, cheese and eggs	0.00	0.13	0.14	0.10
Oils and fats	0.00	0.13	0.12	0.09
Fruit	0.00	0.10	0.11	0.16
Vegetables	0.00	0.06	0.12	0.20
Sugar, jam, honey, chocolate and confectionery	0.00	0.11	0.14	0.12
Food products n.e.c.	0.00	0.10	0.14	0.18
Coffee, tea and cocoa	0.00	0.10	0.11	0.16
Mineral waters, soft drinks, fruit and vegetable juices	0.00	0.16	0.11	0.10
Non-assigned non-alcoholic beverages	0.00	0.13	0.11	0.17
Spirits	0.00	0.16	0.11	0.10
Wine	0.00	0.16	0.11	0.10
Beer	0.00	0.16	0.11	0.10
Non-assigned alcoholic beverages	0.00	0.16	0.11	0.10
Tobacco	0.00	0.16	0.21	0.14
Housing				
Actual rentals paid by tenants	0.00	0.12	0.03	0.04
Actual rentals paid by tenants (second rental)	0.00	0.12	0.02	0.03
Other actual rentals	0.00	0.12	0.02	0.02
Other actual rentals	0.00	0.12	0.02	0.02
Imputed rentals of owner-occupiers	0.00	0.12	0.02	0.02
Other imputed rentals	0.00	0.12	0.02	0.02
Materials for the maintenance and repair of the dwelling	0.00	0.13	0.29	0.53
Services for the maintenance and repair of the dwelling	0.00	0.24	0.05	0.06
Water supply	0.00	0.00	0.00	0.00
Refuse collection	0.00	0.31	0.09	0.18
Sewerage collection	0.00	0.49	0.08	0.11
Other services relating to the dwelling n.e.c.	0.00	0.13	0.02	0.03
Energy				
Electricity	0.00	0.74	0.35	0.07
Gas	2.50	2.22	0.67	0.15
Liquid fuels	2.50	0.43	0.69	0.79
Solid fuels	2.50	0.20	0.28	0.43
Heating energy	0.00	5.84	0.49	0.17
Other heating costs	0.00	2.17	0.53	0.38
Mobility				
Motor cars	0.00	0.02	0.18	0.19
Motorcycles	0.00	0.01	0.14	0.25
Bicycles	0.00	0.01	0.14	0.25
Spare parts and accessories for personal transport equipment	0.00	0.15	0.02	0.03
Fuels and lubricants for personal transport equipment	3.99	0.44	0.60	0.68
Maintenance and repair of personal transport equipment	0.00	0.15	0.02	0.03
Other services in respect of personal transport equipment	0.00	0.08	0.04	0.08
Passenger transport by railway	0.00	0.08	0.04	0.20
Passenger transport by road	0.00	0.08	0.04	0.08
Passenger transport by air	0.00	0.59	0.08	0.18
Passenger transport by sea and inland waterway	0.00	0.09	0.06	0.13
Combined passenger transport	0.00	0.08	0.04	0.08
Other purchased transport services	0.00	0.08	0.04	0.08
Goods				
Clothing materials	0.00	0.04	0.19	0.34
Garments	0.00	0.01	0.20	0.41
Other articles of clothing and clothing accessories	0.00	0.03	0.16	0.35
Cleaning, repair and hire of clothing	0.00	0.09	0.02	0.03
Shoes and other footwear	0.00	0.02	0.17	0.40
Repair and hire of footwear	0.00	0.09	0.02	0.03
Furniture and furnishings	0.00	0.08	0.14	0.28
Carpets and other floor coverings	0.00	0.09	0.14	0.26
Repair of furniture, furnishings and floor coverings	0.00	0.26	0.00	0.01
Household textiles	0.00	0.06	0.14	0.26
Major household appliances whether electric or not	0.00	0.05	0.16	0.21
Small electric household appliances	0.00	0.04	0.18	0.32
Repair of household appliances	0.00	0.17	0.04	0.05

(*continued on next page*)

Table A.1 (*continued*)

	Direct	Indirect		
	AT	AT	EU	World
Glassware, tableware and household utensils	0.00	0.05	0.16	0.29
Major tools and equipment	0.00	0.08	0.03	0.04
Small tools and miscellaneous accessories	0.00	0.09	0.13	0.22
Non-durable household goods	0.00	0.25	0.43	0.54
Domestic services and household services	0.00	0.10	0.02	0.03
Pharmaceutical products	0.00	0.09	0.13	0.41
Other medical products	0.00	0.07	0.14	0.38
Therapeutic appliances and equipment	0.00	0.02	0.11	0.30
Medical services	0.00	0.11	0.04	0.05
Dental services	0.00	0.11	0.04	0.05
Paramedical services	0.00	0.07	0.02	0.04
Hospital services	0.00	0.11	0.04	0.05
Postal services	0.00	0.04	0.01	0.03
Telephone and telefax equipment	0.00	0.02	0.10	0.49
Telephone and telefax services	0.00	0.04	0.01	0.03
Equipment for the reception, recording and reproduction of sound and image	0.00	0.02	0.10	0.49
Photographic and cinematographic equipment and optical instruments	0.00	0.03	0.10	0.47
Information processing equipment	0.00	0.07	0.10	0.19
Recording media	0.00	0.08	0.15	0.27
Repair of audio-visual, photographic and information processing equipment	0.00	0.26	0.00	0.01
Major durables for outdoor recreation	0.00	0.03	0.16	0.23
Musical instruments and major durables for indoor recreation	0.00	0.05	0.13	0.28
Maintenance and repair of other major durables for recreation and culture	0.00	0.06	0.12	0.13
Games, toys and hobbies	0.00	0.09	0.08	0.15
Equipment for sport, camping and open-air recreation	0.00	0.05	0.14	0.29
Gardens, plants and flowers	0.00	0.07	0.18	0.30
Pets and related products	0.00	0.09	0.14	0.21
Veterinary and other services for pets	0.00	0.10	0.03	0.04
Recreational and sporting services	0.00	0.10	0.03	0.04
Cultural services	0.00	0.16	0.06	0.06
Games of chance	0.00	0.10	0.03	0.04
Books	0.00	0.13	0.09	0.05
Newspapers and periodicals	0.00	0.13	0.09	0.05
Miscellaneous printed matter	0.00	0.13	0.09	0.05
Stationery and drawing materials	0.00	0.06	0.13	0.28
Package holidays	0.00	0.12	0.03	0.07
Hairdressing salons and personal grooming establishments	0.00	0.09	0.02	0.03
Electrical appliances for personal care	0.00	0.03	0.17	0.38
Other appliances, articles and products for personal care	0.00	0.05	0.16	0.24
Jewellery, clocks and watches	0.00	0.03	0.09	0.34
Other personal effects	0.00	0.05	0.13	0.29
Services				
Pre-primary and primary education	0.00	0.10	0.03	0.03
Secondary education	0.00	0.10	0.03	0.03
Post-secondary non-tertiary education	0.00	0.10	0.03	0.03
Tertiary education	0.00	0.10	0.03	0.03
Education not definable by level	0.00	0.10	0.03	0.03
Other school-based activities	0.00	0.10	0.03	0.03
Restaurants, cafés and similar	0.00	0.13	0.03	0.06
Canteens	0.00	0.13	0.03	0.06
Accommodation services	0.00	0.13	0.03	0.06
Social protection	0.00	0.11	0.04	0.05
Insurance connected with the dwelling	0.00	0.07	0.03	0.05
Insurance connected with health	0.00	0.07	0.03	0.05
Insurance connected with transport	0.00	0.07	0.03	0.05
Other insurance	0.00	0.07	0.03	0.05
Other financial services n.e.c.	0.00	0.08	0.02	0.03
Other services n.e.c.	0.00	0.12	0.02	0.03

Appendix B. Equivalence approach

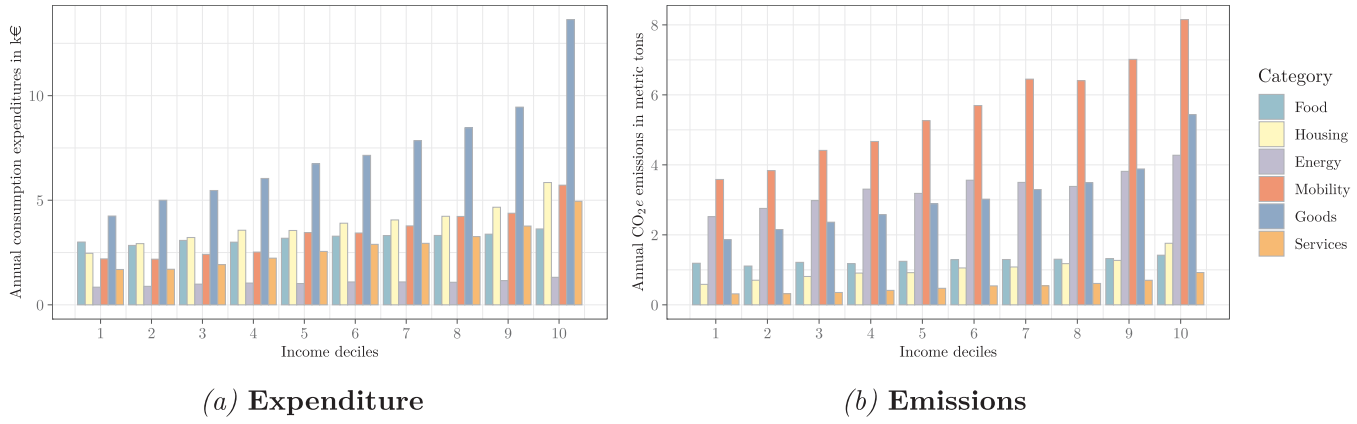

Fig. B.1. Annual equivalized expenditures and CO_2e emissions by consumption category across the equivalized income distribution.
Notes: These graphs show the equivalized annual consumption expenditure on food, housing, energy, mobility, goods, and services over deciles of equivalized disposable income. Housing, mobility, goods, and services significantly increase across the distribution, whereas expenditure on food and energy is comparatively inelastic with respect to income.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

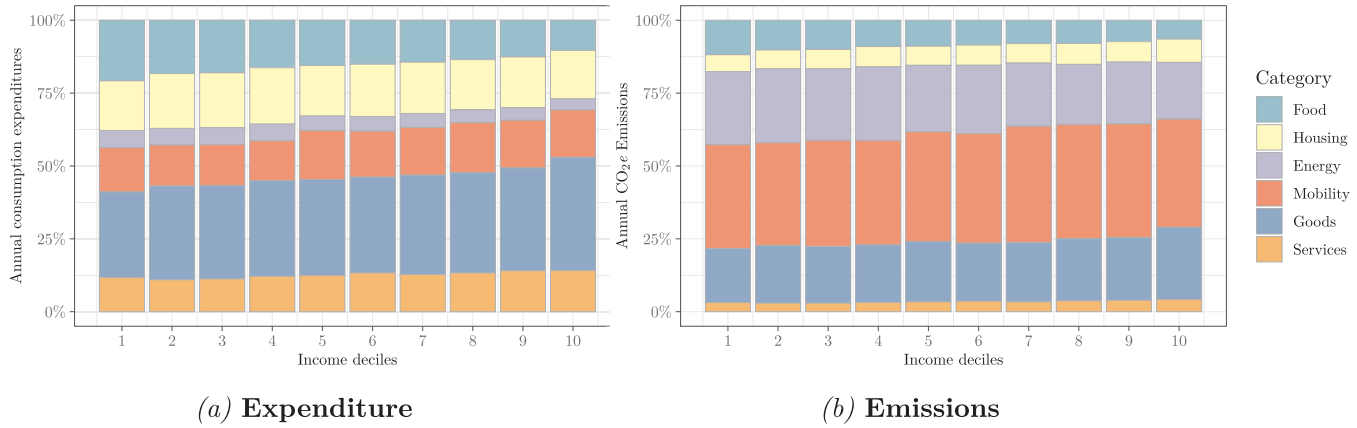

Fig. B.2. Structure of equivalized expenditure and CO_2e emissions by consumption category across the equivalized income distribution.
Notes: These graphs show the proportional composition of equivalized consumption expenditure and CO_2e emissions for six consumption categories over deciles of equivalized disposable income. The relative importance of CO_2e emissions caused by energy and mobility exceed their expenditure shares significantly, whereas housing and services have a subproportional impact on overall CO_2e emissions.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

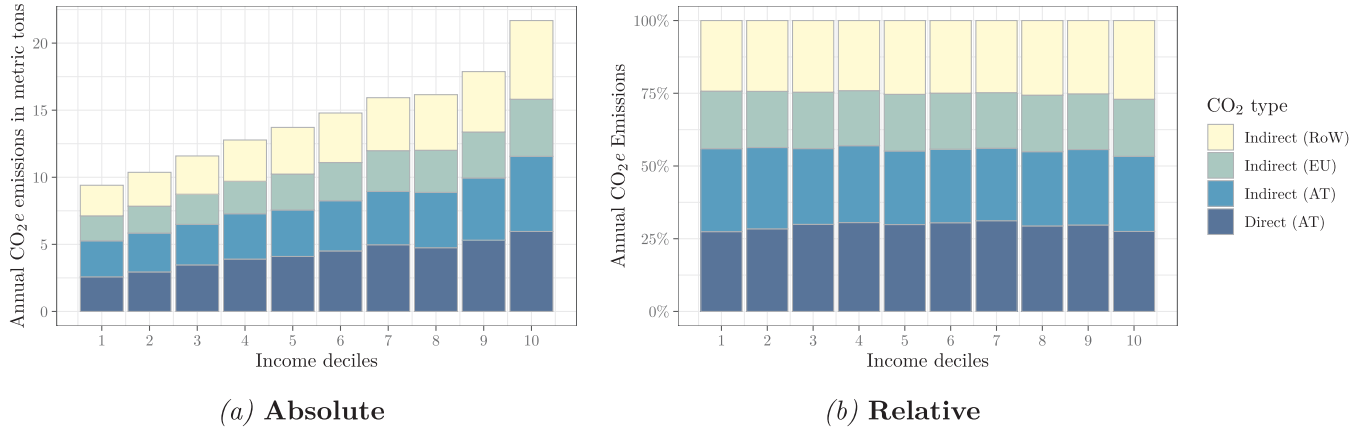

Fig. B.3. Composition of equivalized CO_2e emissions by origin across the equivalized income distribution.
Notes: These graphs show the origin of equivalized CO_2e emissions over deciles of equivalized household income.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

Appendix C. Per capita approach

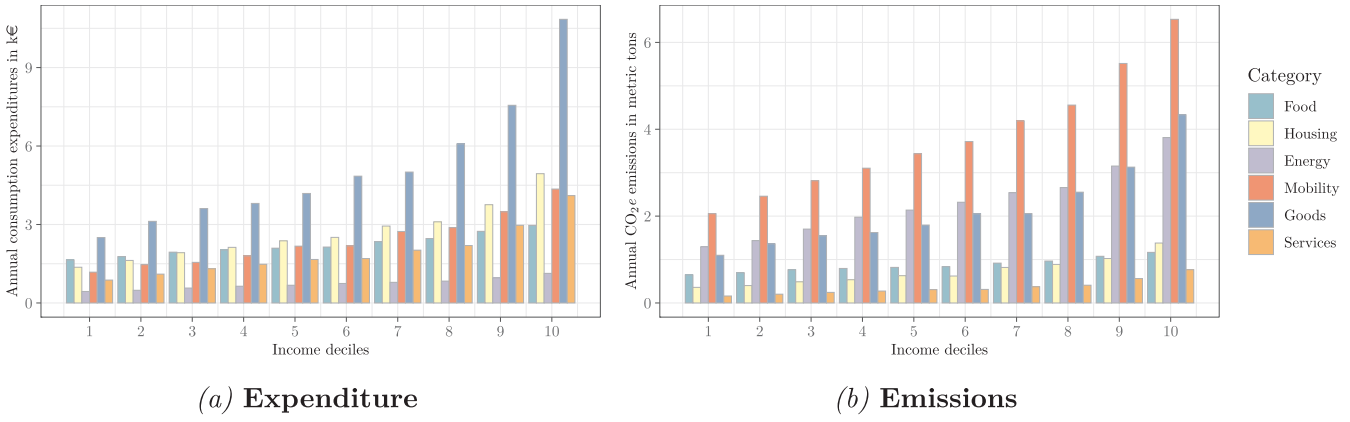

Fig. C.1. Annual per capita expenditure and CO_2e emissions by consumption category across the per capita income distribution.
Notes: These graphs show the annual per capita consumption expenditure on food, housing, energy, mobility, goods, and services over deciles of the per capita income distribution. Housing, mobility, goods, and services significantly increase from one decile to the next, whereas expenditure on food and energy is comparatively inelastic with respect to income.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

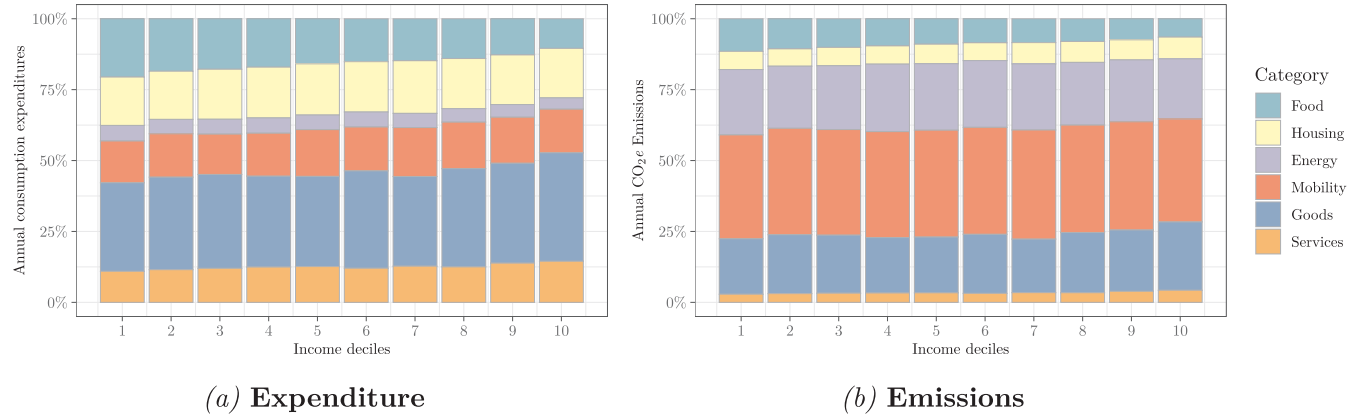

Fig. C.2. Structure of per capita expenditure and CO_2e emissions by consumption category across the per capita income distribution.
Notes: These graphs show the proportional composition of per capita consumption expenditure and CO_2e emissions for six consumption categories over deciles of the per capita income distribution. The relative importance of CO_2e emissions caused by energy and mobility exceed their expenditure shares significantly, whereas housing and services have a subproportional impact on overall CO_2e emissions.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

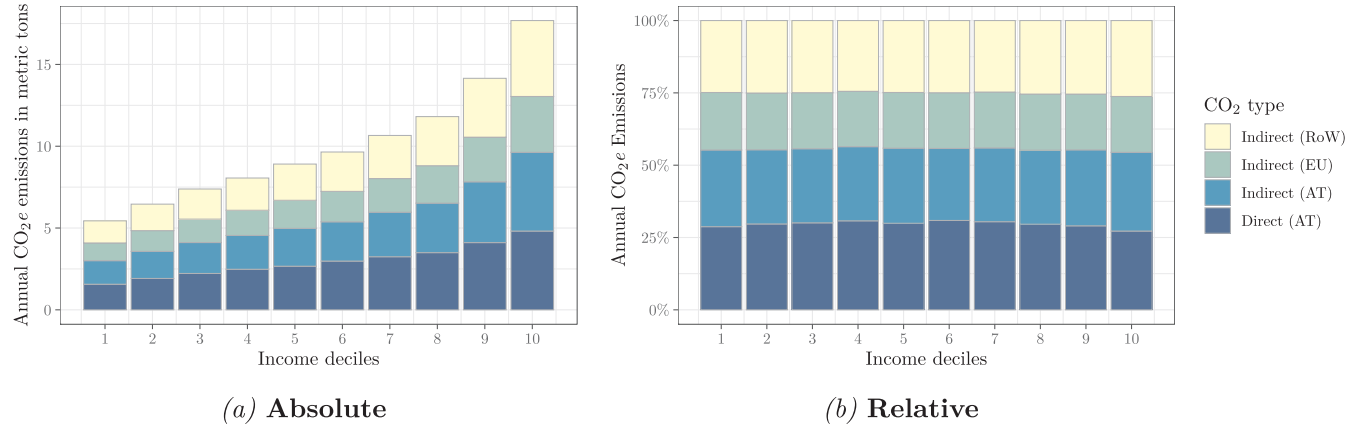

Fig. C.3. Composition of per capita CO_2e emissions by origin across the per capita income distribution.
Notes: These graphs show the origin of per capita CO_2e emissions over deciles of per capita household income.
Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

Appendix D. Descriptive statistics

Table D.1
Descriptive statistics of explanatory variables.

		N	%
Age	31-45y	1817	27.8
	30y and below	730	11.2
	46-60y	2073	31.7
	61-75y	1372	21.0
	76y and above	541	8.3
Gender	Female	3034	46.4
	Male	3499	53.6
Education	Upper secondary	4164	63.7
	Compulsory	1240	19.0
	Post-secondary	425	6.5
	Tertiary	704	10.8
Number of adults	1	2219	34.0
	2	3295	50.4
	3	713	10.9
	4+	306	4.7
Number of children	0	4581	70.1
	1	953	14.6
	2	739	11.3
	3	204	3.1
	4+	56	0.9
Dwelling type	Apartment block	3111	47.6
	Double-family home	966	14.8
	Single-family home	2456	37.6
Year of construction	1970 to 1999	2756	42.2
	1945 to 1970	1724	26.4
	2000 to 2010	692	10.6
	Prior 1945	1361	20.8
Heating system	Central heating	376	5.8
	Coal	223	3.4
	District heating	1160	17.8
	Gas	1981	30.3
	Heating oil	1269	19.4
	Other	196	3.0
	Renewables	163	2.5
	Wood, Pellets	1165	17.8
Urbanization	Medium populated	1645	25.2
	Highly populated	2323	35.6
	Sparsly populated	2565	39.3
Has housing savings plan	False	2119	32.4
	True	4414	67.6
Has shares	False	4993	76.4
	True	1540	23.6

Table D.2
Estimation of socio-demographic factors for CO_2e emissions and tax-to-income ratio.

	Direct emissions			Carbon footprint		
	GHG	Tax/income		GHG	Tax/income	
	t CO_2e	Top 33%	Top 10%	t CO_2e	Top 33%	Top 10%
	(1)	(2)	(3)	(4)	(5)	(6)
Age (ref: 30-45 yrs)						
30y and below	−0.090 (0.261)	0.007 (0.023)	−0.011 (0.016)	−0.298 (0.544)	−0.001 (0.023)	−0.006 (0.017)
45-60y	−0.194 (0.237)	−0.011 (0.018)	−0.016 (0.013)	0.605 (0.492)	0.034 (0.019)$^{+}$	−0.008 (0.013)
60-75y	−0.909 (0.261)***	−0.064 (0.022)**	−0.051 (0.015)***	−0.761 (0.570)	−0.024 (0.023)	−0.032 (0.016)*
75y and above	−1.850 (0.300)***	−0.135 (0.026)***	−0.084 (0.018)***	−3.296 (0.644)***	−0.128 (0.028)***	−0.082 (0.018)***
Gender (ref: female)						
Male	0.389 (0.163)*	0.042 (0.013)**	0.012 (0.009)	0.417 (0.352)	0.014 (0.013)	0.014 (0.009)
Education (ref: upper secondary)						
Compulsory	−0.437 (0.197)*	−0.048 (0.017)**	−0.035 (0.012)**	−1.707 (0.436)***	−0.054 (0.019)**	−0.042 (0.013)***
Post-secondary	−0.137 (0.305)	−0.016 (0.027)	−0.006 (0.017)	−0.146 (0.676)	−0.013 (0.027)	−0.005 (0.016)
Tertiary	−0.039 (0.274)	0.008 (0.021)	0.017 (0.013)	0.498 (0.568)	0.018 (0.021)	0.009 (0.012)
Number of adults (ref: 1)						
2	−0.123 (0.187)	0.022 (0.018)	0.014 (0.012)	1.093 (0.414)**	0.055 (0.018)**	0.035 (0.013)**

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Table D.2 (*continued*)

	Direct emissions			Carbon footprint		
	GHG	Tax/income		GHG	Tax/income	
	t CO_2e	Top 33%	Top 10%	t CO_2e	Top 33%	Top 10%
	(1)	(2)	(3)	(4)	(5)	(6)
3	0.878 (0.385)*	0.075 (0.027)**	0.057 (0.021)**	3.329 (0.840)***	0.079 (0.028)**	0.094 (0.021)***
4+	1.618 (0.535)**	0.093 (0.038)*	0.069 (0.025)**	4.963 (1.164)***	0.162 (0.039)***	0.105 (0.029)***
Number of children (ref: 0)						
1	0.438 (0.302)	0.012 (0.021)	0.004 (0.014)	1.750 (0.623)**	0.039 (0.021)$^{+}$	−0.007 (0.013)
2	0.349 (0.302)	0.024 (0.024)	0.007 (0.016)	1.823 (0.622)**	0.056 (0.024)*	−0.005 (0.014)
3	−0.383 (0.520)	−0.068 (0.036)$^{+}$	−0.029 (0.023)	2.315 (1.067)*	0.028 (0.038)	0.000 (0.024)
4+	0.144 (1.283)	0.022 (0.070)	0.047 (0.056)	1.005 (2.366)	0.070 (0.065)	0.023 (0.041)
Number of cars owned (ref: 0)						
1	3.401 (0.163)***	0.321 (0.016)***	0.158 (0.012)***	6.116 (0.377)***	0.270 (0.018)***	0.133 (0.013)***
2	5.907 (0.288)***	0.450 (0.023)***	0.216 (0.016)***	10.990 (0.622)***	0.367 (0.024)***	0.178 (0.017)***
Floor area						
Square meters	0.006 (0.002)*	0.000 (0.000)	0.000 (0.000)	0.035 (0.006)***	0.001 (0.000)***	0.000 (0.000)**
Dwelling type (ref: apartment block)						
Double-family home	0.657 (0.273)*	0.057 (0.023)*	0.018 (0.017)	0.810 (0.648)	0.039 (0.024)	−0.002 (0.015)
Single-family home	0.853 (0.279)**	0.054 (0.022)*	0.009 (0.016)	0.558 (0.642)	0.016 (0.023)	−0.005 (0.015)
Year of construction (ref: 1970–1999)						
1945 to 1970	0.415 (0.188)*	0.032 (0.016)*	0.011 (0.011)	0.532 (0.406)	0.009 (0.017)	0.010 (0.011)
2000 to 2010	−0.214 (0.338)	−0.014 (0.022)	0.004 (0.014)	0.361 (0.712)	0.010 (0.024)	0.024 (0.016)
Prior 1945	0.206 (0.203)	0.013 (0.017)	0.017 (0.012)	0.185 (0.445)	0.002 (0.018)	0.009 (0.012)
Heating system						
Coal	1.154 (0.453)*	0.163 (0.044)***	0.076 (0.035)*	0.902 (0.920)	0.062 (0.044)	0.089 (0.033)**
District heating	−0.519 (0.327)	−0.028 (0.029)	−0.019 (0.018)	3.313 (0.620)***	0.117 (0.029)***	0.059 (0.017)***
Gas	1.521 (0.307)***	0.087 (0.029)**	0.034 (0.018)$^{+}$	3.296 (0.587)***	0.103 (0.028)***	0.058 (0.015)***
Heating oil	2.142 (0.358)***	0.136 (0.032)***	0.062 (0.020)**	3.295 (0.677)***	0.122 (0.031)***	0.065 (0.017)***
Other	−0.754 (0.412)$^{+}$	−0.075 (0.040)$^{+}$	−0.044 (0.024)$^{+}$	−1.387 (0.794)$^{+}$	−0.015 (0.041)	−0.037 (0.018)*
Renewables	−1.760 (0.623)**	−0.125 (0.044)**	−0.011 (0.029)	−1.985 (1.238)	−0.036 (0.046)	0.017 (0.028)
Wood, Pellets	0.055 (0.381)	−0.006 (0.033)	0.013 (0.021)	−0.920 (0.740)	−0.002 (0.032)	0.014 (0.018)
Urbanization (ref: medium populated)						
Highly populated	−1.097 (0.233)***	−0.087 (0.019)***	−0.009 (0.012)	−1.594 (0.524)**	−0.069 (0.019)***	0.004 (0.012)
Sparsly populated	0.107 (0.208)	0.001 (0.017)	0.026 (0.012)*	−0.543 (0.444)	0.000 (0.017)	0.001 (0.011)
Proxies for the capacity to adjust						
Owns main residence	−0.123 (0.203)	0.008 (0.018)	0.001 (0.012)	0.984 (0.465)*	0.021 (0.018)	0.023 (0.012)$^{+}$
Has a 2^{nd} residence	0.714 (0.381)$^{+}$	0.061 (0.029)*	0.015 (0.016)	2.715 (0.884)**	0.062 (0.028)*	0.005 (0.016)
Has housing savings plan	−0.225 (0.166)	0.004 (0.014)	−0.004 (0.010)	0.222 (0.358)	0.024 (0.015)	0.010 (0.010)
Has shares	−0.363 (0.206)$^{+}$	−0.013 (0.016)	−0.017 (0.010)$^{+}$	0.511 (0.458)	0.012 (0.016)	0.008 (0.010)
Disp. HH income: Decile 2	0.029 (0.185)	−0.020 (0.026)	−0.055 (0.023)*	0.185 (0.413)	−0.162 (0.029)***	−0.121 (0.025)***
Disp. HH income: Decile 3	0.385 (0.222)$^{+}$	−0.069 (0.026)**	−0.102 (0.023)***	1.911 (0.525)***	−0.214 (0.031)***	−0.158 (0.026)***
Disp. HH income: Decile 4	0.068 (0.267)	−0.157 (0.028)***	−0.181 (0.024)***	1.473 (0.564)**	−0.324 (0.031)***	−0.252 (0.026)***
Disp. HH income: Decile 5	0.695 (0.279)*	−0.181 (0.030)***	−0.199 (0.025)***	2.726 (0.604)***	−0.379 (0.031)***	−0.292 (0.026)***
Disp. HH income: Decile 6	1.026 (0.311)***	−0.242 (0.031)***	−0.231 (0.026)***	3.937 (0.669)***	−0.435 (0.032)***	−0.331 (0.027)***
Disp. HH income: Decile 7	1.192 (0.332)***	−0.286 (0.031)***	−0.265 (0.026)***	5.015 (0.723)***	−0.517 (0.033)***	−0.358 (0.028)***
Disp. HH income: Decile 8	1.599 (0.356)***	−0.348 (0.032)***	−0.324 (0.025)***	6.243 (0.790)***	−0.622 (0.033)***	−0.420 (0.028)***
Disp. HH income: Decile 9	1.836 (0.403)***	−0.438 (0.032)***	−0.338 (0.026)***	7.747 (0.896)***	−0.700 (0.035)***	−0.436 (0.028)***
Disp. HH income: Decile 10	3.573 (0.461)***	−0.533 (0.034)***	−0.358 (0.028)***	13.375 (1.020)***	−0.793 (0.035)***	−0.483 (0.029)***
Num.Obs.	6533	6533	6533	6533	6533	6533
R^2	0.371	0.205	0.129	0.458	0.180	0.134
Adj. R^2	0.366	0.200	0.123	0.454	0.175	0.128

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$; $^{+}p < 0.1$.

Source: Austrian HBS 2009/10, EXIOBASE 2010, own calculations.

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