Full Paper

Topic

Equity and emissions. How are household emissions distributed, what are their drivers and what are possible implications for future climate mitigation?

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1. Introduction

Climate change is one of the biggest problems for mankind and a challenge for policy makers worldwide. As a milestone achievement, the Kyoto protocol was adopted in 1997 and 37 industrialised countries introduced greenhouse gas emission reduction targets for the period between 2008 and 2012 within their national borders (UNFCCC, 2013). Renewable energy technologies experience large-scale roll-outs, technological transfers support developing countries and 2013, the already 19th UN conference on climate change brought together policy makers and scientists from almost every country to discuss pathways for a low-carbon future and to limit global warming to 2°C (Zammit-Lucia, 2013).

Yet, global emissions continue to increase rapidly. In 2012, global CO2 emissions increased by 1.4% (IEA, 2013). According to EPA (2013), global emissions increases are even accelerating since 2000. A few weeks after passing the historical record of 400 parts per million of CO2 in the atmosphere (Montaigne, 2013), the Intergovernmental Panel on Climate Change (IPCC) released the first part of the 5th assessment report on climate change in September 2013. The report shows that if global emissions remain steady, the world is heading towards a global temperature increase of between 2.6C to 4.8C by the end of the century. (IPCC, 2013:25).[1]

A temperature increase of four degrees world would be catastrophic for the planet and humankind. Important tipping points in the global climate could be crossed. Heat waves, devastating sea-level rises and severe bad harvests are only the most direct consequences (PIK, 2012). World Bank president Kim commented: “A 4 degree warmer world can, and must be, avoided – we need to hold warming below 2 degrees” (World Bank, 2012).

To stay within the 2°C threshold, CO2 emissions would have to remain within the range of around 1.000 Gt (Harvey, 2013).[2] By 2011, two thirds of this budget has already been reached. If yearly emissions remain at current levels, it will likely be exhausted within the next 15 to 25 years (Harvey, 2013; IPCC, 2013:21). Therefore, policy measures must induce rapid emission reductions at an unprecedented pace to avoid dangerous warming beyond 2°C.

The time window is closing. According to a report by PwC (2012), the global carbon intensity (CO2/unit of GDP) was only decreasing by 0.8 % between 2000 and 2011 (PwC, 2012). To meet the 2°C target and remain within the carbon budget, an immediate 6% annual decrease of carbon intensity of the global economy until 2100 would be required (PwC, 2013). Anderson and Bows-

1 Compared to 1986–2005 levels.

2 Between 820-880 GtCO2 if other greenhouse gases are accounted for (Harvey, 2013).

Larkin (2011; 2013) calculate that for Annex I countries, a reduction rate of unprecedented 8-10% p.a. would be necessary. This could only be achieved by a degrowth strategy from wealthy nations.

Thus far, the majority of policy measures in industrialised countries, including Germany, have focussed on the supply side of energy. Further policy options exist, including the phase-out of fossil-fuel subsidies and energy efficiency improvements in the building sector, industry and transport as well as the utilisation of best available sustainable technologies (IEA, 2013).

However, several climate scientists have argued that emission reductions at this rate cannot be delivered by technical supply-side solutions alone (Anderson and Bows-Larkin, 2013; Barrett, 2013; Barrett et al., 2013; Helm, 2012a). Druckmann (2013:26) argues that “technological change is not enough to achieve the radical emissions reductions required: lifestyles also need to change.” Therefore, further demand-side policies have been advocated:

> *“[L]ow-carbon supply technologies cannot deliver the necessary rate of emission reductions – they need to be complemented with rapid, deep and early reductions in energy consumption”* (Tyndall°Centre, 2013)

Households cause the majority of emissions on a consumption basis. Globally, around 72% of emissions were related to goods and services consumed by households (Hertwich and Peters, 2009). In Germany, nearly 69% of emissions are caused by household consumption (Mayer and Flachmann, 2011).

However, not all households contribute equally to climate change. Previous analyses for the UK show that the carbon footprint is unevenly distributed, not only on an international level (Büchs and Schnepf, 2013a; Druckman and Jackson, 2009; Galli et al., 2011; Gough et al., 2011; Preston et al., 2013). Some households contribute significantly more to climate change. Other households already have a rather sustainable footprint.

Despite the relevance of households, the knowledge of how emissions are distributed over households is still very limited, also due to methodological and data limitations (Gough et al., 2011). Until now, no previous study exists for Germany, the largest emitter within the EU. This paper addresses the research gap by answering the questions of how emissions are distributed over household types in Germany and what the socio-economic drivers of emissions are.[3] Moreover, the implications for future policies aiming at the decarbonistion of consumption are discussed. Sufficiency measures are only one of many options on the table, however.

3 This paper is based on an MSc dissertation written at the University of Sussex in cooperation with the Environmental Policy Research Centre in Berlin.

2. Why carbon consumption of households matters

The observable mitigation success of most Annex B countries, including Germany, only holds true from a territorial accounting perspective. Existing international climate policy follows a territorial/production-based accounting approach. Under the IPCC "accounting rules, mitigation only applies to 'greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction'" (Peters et al., 2011:1).

Consumption-based accounting (CBA) on the other hand allocates the emissions to consumers and measures emissions along the production, distribution and consumption chain. CBA accounts for trade-embodied emissions which can make an important difference regarding a country's emission carbon footprint.

Looking at emissions from a consumption perspective, the alleged success of Kyoto appears less clear. Large shares of emissions were "outsourced" to emerging economies (Bruckner et al., 2010; Helm, 2012a; Nakano et al., 2009; Peters et al., 2011).

According to an OECD report, Germany counts the fourth highest CO2 trade deficit with 147 MtCO2 in 2000. The consumption-based footprint of Germany in 2000 was 18% higher than under IPCC territorial accounting (Nakano et al., 2009). Similarly, Davis and Caldeira (2010:2;5) found that Germany net-imported 233 MtCO2 in 2004, despite carbon-intensive exports, e.g. through the car industry (ibid.). Bruckner et al. (2010) find increasing CBA emissions for Germany – from 1023 MtCO2 in 1995 to 1061 MtCO2 in 2005. This levers out emission reductions under the UNFCCC treaties. For most Annex B countries, the net-imported GHG exceeds the emissions saved under national mitigation measures (Nakano et al., 2009:3).

While further research is necessary and data improvements are mandatory to obtain an accurate picture of emissions on a consumption basis, the literature suggests that the carbon footprint of Germany has not, or significantly slower, been reduced on a consumption basis. This puts the focus on households.

Household emissions

On a consumption basis, households are the main contributors to climate change. In Germany, 69% of emissions have been associated with household consumption in 2007 (Mayer and Flachmann, 2011).

Household emissions arise directly through the consumption of heating fuels, electricity consumption and vehicle fuels (e.g. petrol and diesel), and indirectly by the consumption of goods and services which all contain a certain amount of emissions “embodied” through various steps of the production and distribution chain, from resource extraction to sales services (Chitnis et al., 2013, submitted:4; Mayer and Flachmann, 2011:36).

Just as emissions are not evenly distributed over industrial sectors on a production basis, nor are they on a consumption basis.

> *“Processes causing greenhouse gas (GHG) emissions benefit humans by providing consumer goods and services. This benefit, and hence the responsibility for emissions, varies by purpose or consumption category and is unevenly distributed across and within countries”* (Hertwich and Peters, 2009).

Based on the Pareto principle, Anderson (2013:108) estimates that globally, between 40 – 60% of emissions arise from only 1 to 5% of the population. Barthel (2006) finds that depending on the lifestyle, very different carbon footprints are possible.

More recently, the association between household emissions and socio-economic factors has been assessed. According to Schoer et al. (2006:2), environmental pollution is significantly influenced by socio-economic factors such as the number of household members and household structure. Consumption and expenditure patterns vary for different household types, and so do associated emissions:

> *“To the extent that consumption patterns vary across different socio-economic groups – both in terms of magnitude and composition – it is possible to assess the underlying socio-economic drivers of environmental quality by identifying the impact of different household types on the environment”* (Pye et al., 2008:25).

Before conducting our analysis for Germany, findings from previous literature are summarised.

3. Literature review

Previous literature on the distribution of emissions largely focuses on OECD countries, predominantly the UK. Earlier work was limited to the analysis of direct emissions (Gough et al., 2011:1). Only recently, studies have broadened the scope to the distribution of total emissions but comparatively few publications exist (e.g. Gough et al. 2011; Büchs and Schnepf, 2013a; Druckman and Jackson, 2009).

Previous findings

Analyses for the UK have shown that both direct and indirect emissions are unequally distributed over different household groups (Gough et al., 2011:40; Büchs and Schnepf 2013a; Druckman and Jackson, 2009; Chitnis et al. 2013, submitted).

Three main assumptions can be drawn from the literature. Firstly, certain emission domains are more skewed than others. Büchs and Schnepf (2013a:118) found that emissions from flights are for instance more concentrated than home energy emissions. While the median of flights is as much as 1.13 tCO2 per household, almost 60% of the UK households did not fly at all in during the survey period.

Secondly, income and household size are often assumed to be the main factors influencing household emissions. However, a broad range of other potentially influential factors including age, household type, social status, education, spatial location have been discussed in the literature with regards to their associations to emissions (Büchs and Schnepf, 2013a:115). Druckman and Jackson (2009) for instance find above-mean emissions for households from prospering suburbs and the countryside and below-mean emissions for multicultural and urban households.

A third important insight from the literature is that the associations between socio-economic factors and emissions vary for different emission types. Weber and Perrels (2000) find that while transport emissions significantly differ between young and elderly households, this is not the case for emissions embodied in clothing.

The exemplary relationship between two key socio-economic factors and emissions is summarised in the following.

Income

Income has been found to be correlated with all types of emissions while some associations are stronger than others. With rising income the purchasing power of household entities increases. While the demand for certain consumables is saturated at a certain level (one cannot heat ones home beyond a certain limit), this does not apply for all goods and services. A limit are diminishing returns. However, this does not necessarily affect the accumulation of goods.

Especially transport emissions have been found to rise relatively proportionally with income (Büchs and Schnepf 2013a: 118). The income elasticity of home energy emissions on the other hand is significantly less (ibid.:119).

Saunders (2011) found that indirect energy and thus, emissions are more strongly correlated with household income than direct emissions are. “This suggests that as incomes rise, so will the relative significance of embedded energy [and related emissions] use” (ibid.:10).

However, a considerable variation of emissions within income deciles indicates that other factors beyond income influence their distribution (Gough et al., 2011:20).

Household size

For household size, the general assumption is that the total demand for goods and services increases in bigger households. On a per capita basis, however, the theory suggests that the demand for energy and associated emissions decreases due to the economies of scale (ibid.:14).

> *“Bigger households consume far less energy per capita than small households. A person in a single household consumes almost 60 % more energy than average, whereas a person in a three-and-more person household consumes almost 30% less than average”* (Mayer, 2009:10).

The correlation between household size and emissions appears to be strongest for home energy (Büchs and Schnepf, 2013a:118) For other emission domains the relationship is less stringent. Gough et al. (2011:14) find no significant correlation between the per capita emissions of transport and consumables and household size. Generally, children show a different effect on household emissions than adults.

Whether other socio-economic factors than income and household size are significant with regards to emissions has been controversially discussed in the scientific literature (Büchs and Schnepf, 2013a:115). Based on an extended literature review we also included employment status, age, education, spatial location, gender, social status, marriage and other socio-economic factors in our analysis.

4. Methodology

The analysis maps the CO2 intensity (kgCO2/€ of expenditure) derived from an environmentally extended input-output model (EE IO) and separate calculations for home energy against the expenditure categories of the 2008 sample survey of income and expenditure (EVS micro data for 44082 households).

The EE IO model used in this analysis has been developed by the Federal Statistical Office of Germany (Mayer and Flachmann, 2011). We use updated and unpublished data for 2008 which has been provided to us by Christine Flachmann (Mayer and Flachmann, 2013).

The authors use an environmental accounting approach which, in addition to territorial emissions, accounts for CO2 emissions from international aviation and transport, biomass combustion and the sum of transport emissions from fuel purchase abroad minus fuel purchased in Germany from non-residents, all of which remain neglected under the IPCC accounting concept (Mayer and Flachmann, 2011:12). The approach only captures private consumption, neglecting public emissions (e.g. infrastructure) and work-related emissions (e.g. business flights).

The EE IO model covers emissions from 14 supplier countries and 73 different industries. These account for 67.5 % of goods imported to Germany in 2006 (ibid.). CO2 emissions embodied in upstream goods used in supplier countries are neglected. The model therefore significantly underestimates imported emissions. However, it provides the best available data since no applicable multi-regional input-output model has been developed for Germany thus far.[4]

4.1 Calculating CO2 coefficients

The CO2 intensity of consumption varies for different expenditure categories. While some products and services require a large amount of energy to be produced and transported, other products and services only require a small amount of energy.

On the basis of Mayer and Flachmann (2013), the CO2 intensities (kgCO2/€) are calculated by relating private household expenditure to consumption-embodied CO2 (see table 1). This provides us with a total of 25 different CO2 coefficients. The calculations are shown in Not all of these coefficients can be applied to the EVS household expenditure data due to a reclassification process as described in chapter 4.3.

To achieve more accurate results, separate calculations for home energy emission intensities are conducted as recommended by Büchs and Schnepf (2013b). Annual average prices per kWh for 2008 are taken and related it to the average embodied emissions per kWh. This also provides us with the average CO2(e) intensity in kgCO2(e) per € of expenditure (see table 2). Since some external sources provide the CO2e values per kWh, we display CO2(e) in the later analysis.

Put simply, each € spent on services causes the relatively least emissions, followed by products and food. The highest CO2 intensity exists for home energy expenditure and transport (see figure 1).

4 Comparable analyses for the UK use multi-regional input-output models which include more detailed information about trade-embodied emissions.

CPA		Private household Expenditure in Mill. EUR	Embodied CO2 in Mill. T	CO2 Intensity in kg/€	
CPA	**Household final consumption and expenditure**	**1,339,850**	**619.976**	**0.463**	
	Products	**275,808**	**77.712**	**0.282**	
17-18	Textiles, furs	82,336	18.221	0.221	
21.22	Paper, publishing	31,918	10.209	0.320	
24-25	Chem. prod, rubber, plastic	41,238	14.845	0.360	
30-33	Office and elect. machinery	32,860	7.137	0.217	
36-37	Furniture, jewellery, musical instruments etc.	44,737	10.775	0.241	
	Other products	42,719	16.524	0.387	
	Food	**216,446**	**74.713**	**0.345**	
1	Agricultural products	26,531	12.173	0.459	
15	Food., tobacco	189,915	62.540	0.329	
	Transport	**175,800**	**158.752**	**0.903**	
34	Motor vehicles and equipment	67,091	26.815	0.400	
50	Trade, repair services of vehicles	21,469	2.833	0.132	
NA	Fuel (direct)	46,870	94.843	2.024	
	Transport Services		*34.261*		
60.2	Road Transport	6,100	6.905	1.132	
60.1	Transport via railways	10,608	4.940	0.466	
61	Water transport	2,240	1.157	0.516	
62	Air transport	13,840	18.687	1.350	
63	Auxiliary transport services	7,582	2.573	0.339	
	Habitation	**295,954**	**239.593**	0.810	
70	Real estate services	228,564		0.000	
	Energy direct	**67,390**	**121.904**	**3.555**	*uncertainty*
10	Coke	729	4.327	6.236	*over split*
11	Natural gas	18,749	52.667	2.937	*between*
23	Heavy fuel, light fuel, liquid gas	15,703	42.026	3.687	*direct and*
40.1-3	Electricity, district heating	31,520	0.000	3.092	*indirect*
NA	Biomass, other renewable energies	689	22.885	33.214	*energy use*
	Energy indirect		**117.689**		
10	Coal		0.219		
11	Natural gas		2.395		
23	Coke, mineral oil products		15.867		
40.1/3	Electricity, district heating		97.454		
	Services	**375,842**	**69.205**	**0.184**	
NA	Repair services of consumer goods	5,068	0.000	0.000	
55	Hotel, restaurant services	73,027	17.873	0.245	
85	Health services and social work	59,724	7.815	0.131	
65-95	Other services	238,023	43.518	0.183	

Table 1: Calculating CO2 coefficients on the basis of private household expenditure and embodied CO2 emissions

Source: Own illustration based on IO tables for 2008 by Mayer and Flachmann (2013)

	Average prices in 2008 [€/Kwh]	Average embodied CO2(e) [gCO2(e)/kWh]	Average CO2(e) intensity [kgCO2(e)/€]
Electricity 1)6)	0.220	592	2.697
Gas 1)7)	0.0762	254	3.333
Light fuel oil 2)7)	0.076	302	3.992
Liquid gas 3)7)	0.090	285	3.161
District heating 4)7)	0.083	130	1.574
Wood pallets 5)7)	0.038	33	0.873

1) Eurostat (2013b, 2013c)
2) 64,08 €/hl (excl. VAT) (Statistisches Bundesamt, 2013)
3) Facilities to 3000l: 50ct/l (excl. VAT) (Bund der Energieverbraucher, n.d.)
4) Net mixed price for 160kW consumption: 69,39 € (excl. VAT) (AGFW, 2012)
5) Average prices 189€/t (incl. Tax) (DEPV, 2013)
6) CO2 intensity for 2008, (Icha, 2013:2)
7) CO2 intensities for 2004 (Schächtele and Hertle, 2007:31)

Table 2: Calculating CO2 coefficients for home energy on the basis of price data and embodied CO2 emissions

Source: Own calculations.

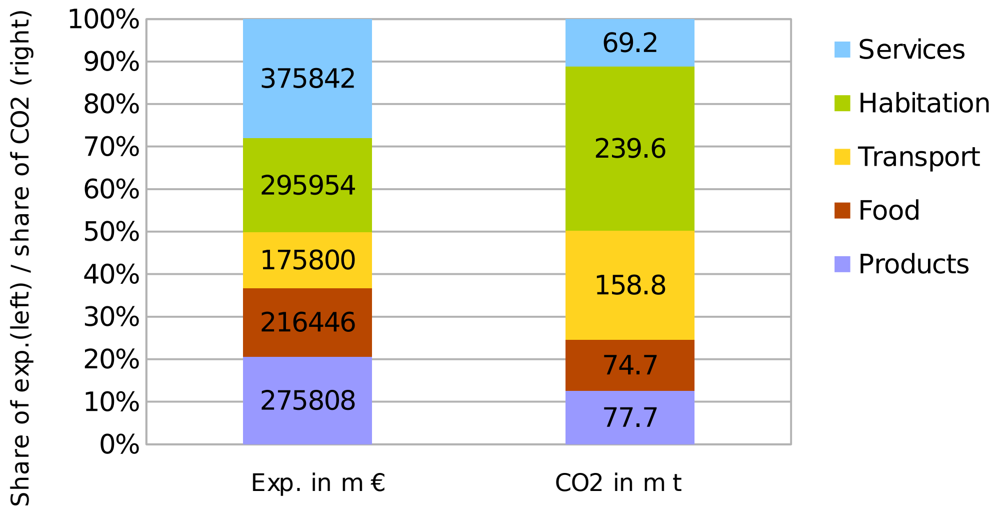

Figure 1: Shares of five different consumption categories of total household expenditure and related total CO2 emissions in Germany, 2008

Source: Own illustration based on Mayer and Flachmann (2013)

4.2 Data set description– richness and limitations

The main data source we use is the representative 2008 sample survey of income and expenditure (Einkommens- und Verbrauchsstichprobe: EVS). It contains information about the household's income situation and expenditure over a period of three consecutive months as well as various socio-demographic characteristics (Federal Statistical Office, 2013a, 2013b:5). We are very grateful to the Environmental Policy Research Centre for making the data access possible.

This analysis uses an 80% anonymised sub-sample of the EVS which contains data of 44088 households. The anonymisation includes adjustment of rare household characteristics standing out (the highest and bottom five characteristic attributes of income, wealth and expenditure categories are therefore presented as their mean value) and the exclusion of nationalities with less than 50.000 people in Germany.[5]

A generic limitation is that expenditure does not equate with consumption. Food for instance can be stored over periods of time. In regards to long-living goods such as cars it is especially important to consider the infrequency of purchase problem (Büchs and Schnepf, 2013b:4). Survey expenditure data might distort the overall-picture of actual consumption. Households with high expenditure on long-living goods might just coincidentally have purchased something within the three months survey period. As the EVS covers a survey period of three months, the problem is expected to be less prevalent, though.

4.3 Data reclassification

A methodological constraint of this work is the fact that the IO model used to generate CO2 coefficients is differently categorised as the EVS expenditure data to which the coefficients are applied to. The expenditure data is categorised in SEA 98 (*Systematisches Verzeichnis der Einnahmen und Ausgaben der Privaten Haushalte*) which is based upon the international classification system COICOP 95 (*Classification of Individual Consumption by Purpose*) (Federal Statistical Office, 2013b:10). The IO model by Mayer and Flachmann (2011) on the other hand uses CPA 2002 (*Statistical Classification of Products by Activity in the European Economic Community*). The EU RAMON project developed correspondence tables for conversion. However, the categories are in many cases not fully congruent, leading to a certain loss of data as well as loss of accuracy of the remaining information.

The general approach is to re-classify the EVS expenditure categories (SEA98/COICOP) into their CPA counterparts. No re-classification table exists for a direct conversion from SEA 98/COICOP 95 – CPA. Therefore, the correspondence table COICOP 1999 – CPA 2002 is used and potential changes between COICOP 1995 and 1999 are neglected (eurostat, 2013a).

5 Further modifications are described by the Federal Statistical Office (2013b:45 ff.).

The categories do not fit equally well. The best fit exists for transport while sub-categories of services, food and products are worse with plenty of EVS categories being split over the respective CPA sub-categories. If categories have no 1:1 fit, it is decided individually upon each case whether this is still included in the model. The main criterion is that the majority of the COICOP category is covered by the relevant CPA counterpart. If the split is rather insignificant, the category remains within the model. If not, they are excluded to avoid flawed results. Additionally, we check whether COICOP categories are split over several CPA categories which would be problematic as different CPA categories have different CO2 coefficients.

For food, products and services, the majority of EVS (COICOP) variables are split over too many sub-categories of their CPA counterparts to apply the CO2 coefficients of their sub-categories. Instead, three meta CO2 coefficients for food, products and services are used. As a result, less carbon-intensive commodities such as textiles and furs are assigned with the same CO2 coefficient as more carbon-intensive products such as chemical products, rubber and plastics. This reduces the accuracy of our calculations in these three fields.

For transport also, the re-classification does not produces the best possible results. Due to the re-classification, the differentiation between public rail-bound and public road-bound transport services is lost. Here, one overall CO2 coefficient for public transport services on the ground, one for air traffic expenditure and one for personal car usage are applied.

For home energy categories, the custom CO2 coefficients as discussed above are applied. These provide a good fit with the data. However, the EVS data does not differentiate between expenditure coal and wood expenditure. Therefore, we exclude households which use “solid fuels” as the main source of energy for their home. This excludes 1778 of 44088 households. The remaining households with emissions from this area are expected to rather have a wood-fired oven (e.g. masonry heater) than a supplementary coal-fired furnace. We hence apply the emission factor for wood pallets to the remaining expenditure in from this category.

Despite the loss of data due to the re-classification, the model still covers 42260 of 44088 cases and 90.001% of total household expenditure. Since the most CO2-intensive categories transport and home energy have relatively very little loss, we still have an overall good fit and coverage of household emissions. The results later show that indirect emissions are further underestimated, however. The full details of the re-classification process are gladly provided by the authors upon request.

4.4 Statistical methods

The statistical analysis is formed of two parts. Firstly, selected descriptive statistics and bivariate analyses are conducted to show the distribution of emissions and explore the relationship between emissions certain socio-economic factors and emissions from different domains. Lorenz curves are created to illustrate the uneven distribution of different kinds of emissions.

Bivariate analyses then include socio-economic factors. Bar charts are created to show emissions in relation to certain socio-economic factors. The statistical differences are assessed by using one-way welch ANOVA analysis. ANOVA is a parametric technique to compare the means of two or more groups. To investigate between which group means differences exist, additional Dunnett's T3 post-hoc tests are used (Pallant, 2011:105).

The relevance of different socio-economic groups with regards to their share of total households and share of total emissions is furthermore visualised.

Secondly, a multivariate linear regression analysis is conducted to draw further statistical inferences upon the relationship between socio-economic factors and emissions. For this analysis a hierarchical regression is most applicable. With variables entered in blocks, one can assess the change of the predictive value of the model after controlling for those variables entered in a previous step (Pallant, 2011:149).

Based upon our hypothesis that income and household size are the main predictor variables for emissions, two blocks are used for the hierarchical regression model. The first block consists of income and household size, differentiated between number of children and adults.

We recode most variables to natural logarithm variables due to non-normality problems. Logarithmic manipulation is only possible for positive values. Therefore, households with a disposable income of less than 1€ are excluded from the analysis. Income, along with number of adults, number of children as well as living area in m^2 are used as metric variables. The remaining independent variables are coded as dummy variables, including age and municipality size. The codebook can be requested from the authors.

For the dependent variables of which we also generate the logarithmic values, our data set has a problem with zero-inflation as many households have no expenditure in some categories. To avoid this problem, the formula $ln(x+1)$ as suggested by Field (2009:80) is used.

Multivariate regression is very sensitive to outliers, extreme data on both ends of the distribution (Pallant, 2011:151 f.). As these are extreme values, they “pull” the regression model towards themselves and thereby reduce the explanatory value for the non-outliers. Here, outliers are excluded based upon the Stem-and-Leaf plot.

For the total and indirect CO2 emissions models, outliers which have higher total emissions than 7788 kgCO2(e) per quarter are excluded. This reduces the sample size to 39867 cases. For transport emissions, the best model fit has been achieved without excluding outliers (42260 cases). For home energy, outliers lower than 4.7 and higher than 9.1 are excluded based on the Stem-and-Leaf plot for logarithmic home energy emissions (39059 cases). For descriptive and bivariate analysis a sample size of 42260 cases is used, which only excludes households which use solid fuels as the main source of heating as discussed in the previous chapter and those with a disposable income of less than 1€.

5. Results

The reclassification process and the limitations of the applied EE IO model leads to an underestimation of indirect emissions – especially for food, products and services. Mean indirect emissions account for only 39.1% of total emissions which is 7% less than before the re-classification. This can partly be explained by the loss of 10% of expenditure data as described in chapter 4.

Flight emissions are unexpectedly small. This is presumably caused by the fact that the analysis only measures private consumption and that holiday flights are often listed under services in the EVS data. Moreover, total emissions in our model are presumably lower than in reality. According to the analysis, the annual mean household emissions amount to only 13.8 tCO2 which is only 1-3 tCO2 higher compared to what Schächtele and Hertle (2007) and Bruckner et al. (2010) calculate as the mean per capita emissions in Germany.

With regards to the analysis of relative differences between household groups as well as the analysis of the drivers of emissions the results are – under the given precaution – estimated to be representative and relatively precise.

5.1 Concentration of emissions

Our descriptive analysis confirms previous results for the UK – emissions are highly concentrated. We find that the median annual emissions of 11.5 tCO2 per household are significantly exceeded by the mean of 13.8 tCO2. The picture is similar for transport (median: 3.0 t, mean: 4.1 t), home energy (median: 4.0 t, mean: 5.6 t) and indirect emissions (median: 4.2 t, mean: 5.4 t).

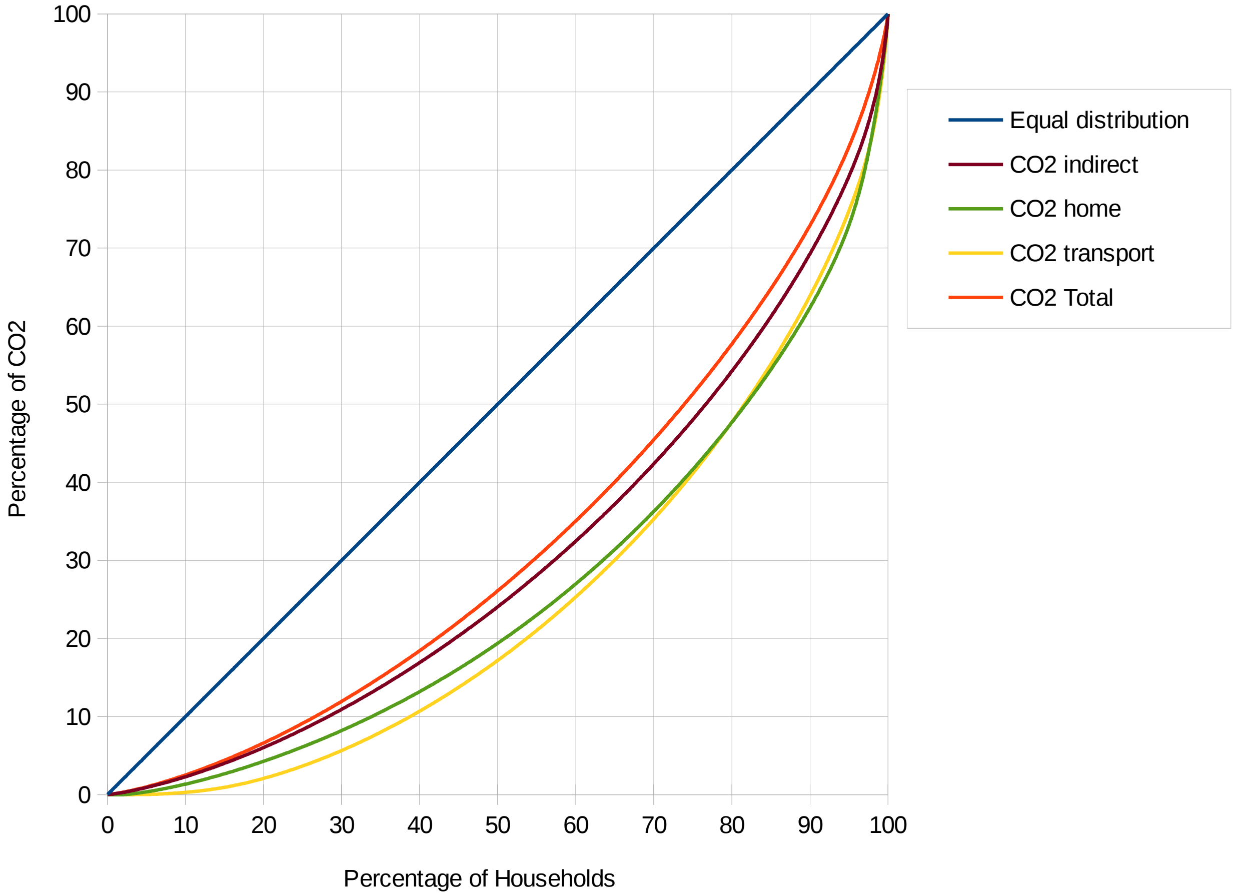

Figure 2: Lorenz curves of household CO2 emissions

The concentration of emissions has been calculated and visualised by using Lorenz curves (figure 2). For emissions from home energy and transport the results indicate that only 20% of households cause more than 50% of associated emissions. On the bottom end, 50% of households emit less than 20% of transport and home energy emissions. Total emissions are less concentrated. The highest 20% of household emitters cause more than 40% of emissions while the least emitting 40% of households cause less than 20% of total emissions. This could indicate that households which have high emissions in the area of transport have generally less home energy emissions and vice versa. Results of per-capita emissions have not been tested with Lorenz curves. The economies of scale effect is therefore not shown.

5.2 Differences between household groups

The analysis confirms that emissions are unevenly spread over household types. Some household types are high emitters, including high-income households, self-employed households, highly educated households, rural households as those where the main income earner (MIE) is aged between 45 and 55. Low-emitting households include low-income households, students and unemployed households, female-headed households and households from the city states.

The ANOVA test results confirm that the differences between the annual total mean emissions are highly significant at the $p < 0.05$ level for all compared socio-economic groups.

The analysis moreover shows that different household types have a different composition of CO_2 emissions. For high-income groups, the share of indirect emissions is higher and especially transport-embodied, product, service emissions increase along income. Over federal states, the different energy infrastructure is visible. Households in South Germany e.g. have a high share of emissions from fuel oil. Urban dwellers have significantly less heating and car fuel emissions than rural dwellers. As MIE of households get older, the share of heating emissions significantly increases while that of car fuel emissions decreases.

Exemplary results are discussed in the following. It has to be mentioned that descriptive analysis does not allow to draw any inferences upon whether these factors are significantly influencing emissions.

5.2.1 Income and emissions

Figure 3 shows how emissions are distributed over disposable income deciles. We find a nearly factor five difference between the highest and lowest income deciles. The ANOVA posthoc test Dunnett T3 shows statistically significant differences between all compared groups at the $p < 0.05$ level.

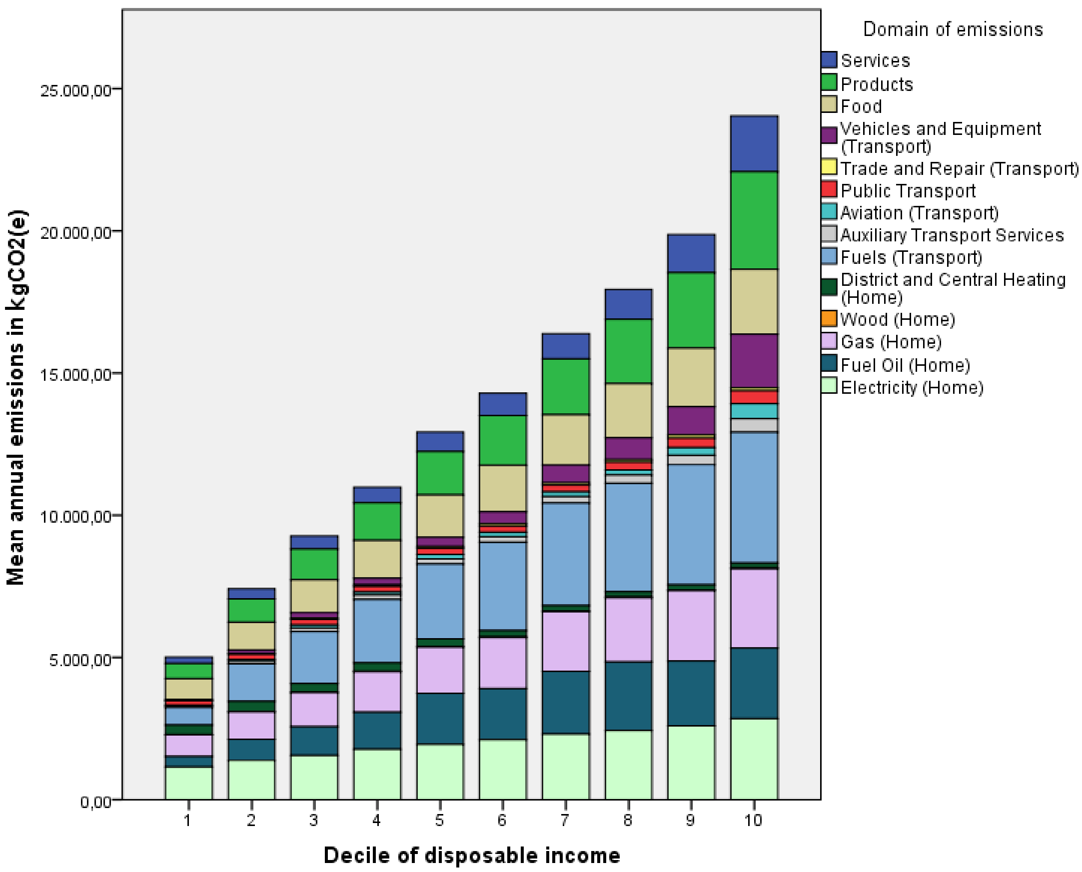

Figure 3: Emissions in kgCO2(e) of different disposable income deciles of households

Figure 4 shows a declining relative relevance of emissions from electricity, public transport, food and as district and central heating. The share of emissions from services, products, other transport emissions such as fuels, aviation and vehicles and equipment on the other hand increases. Interestingly, the share of direct emissions compared to indirect emissions is relatively steady for income deciles 1 through to 7 at around 65-70% and declines thereafter with an increasing relative relevance of indirect emissions, composing nearly 50% of the emissions of the highest income decile. The results have to be considered with caution, given that our model under-estimates indirect emissions. The difference between the lowest and highest income decile could be even higher if trade-embodied emissions were more accurately modelled.

Figure 5 shows the share of each group of households – in this case equally sized income deciles – of total households in comparison to each household group's share of total household emissions. The highest income decile causes 17.4% of total household emissions while the bottom income decile is only responsible for 3.63% of emissions.

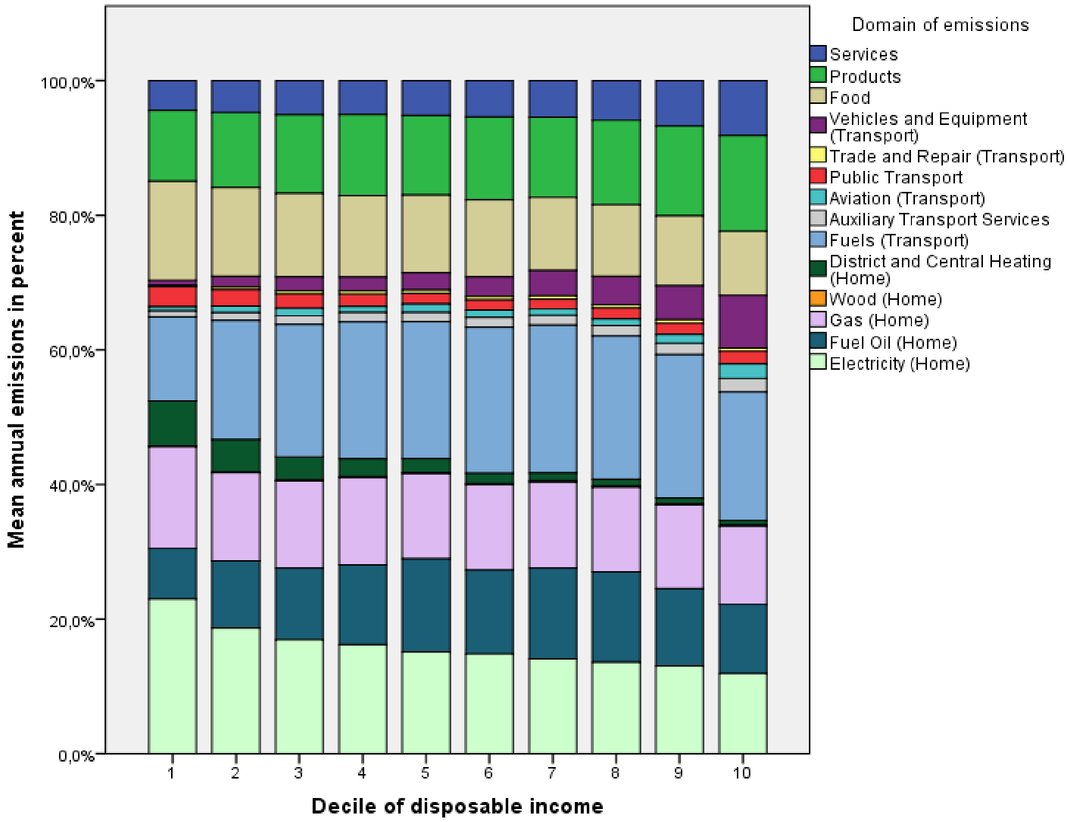

Figure 4: Emissions in percent of different disposable income deciles of households

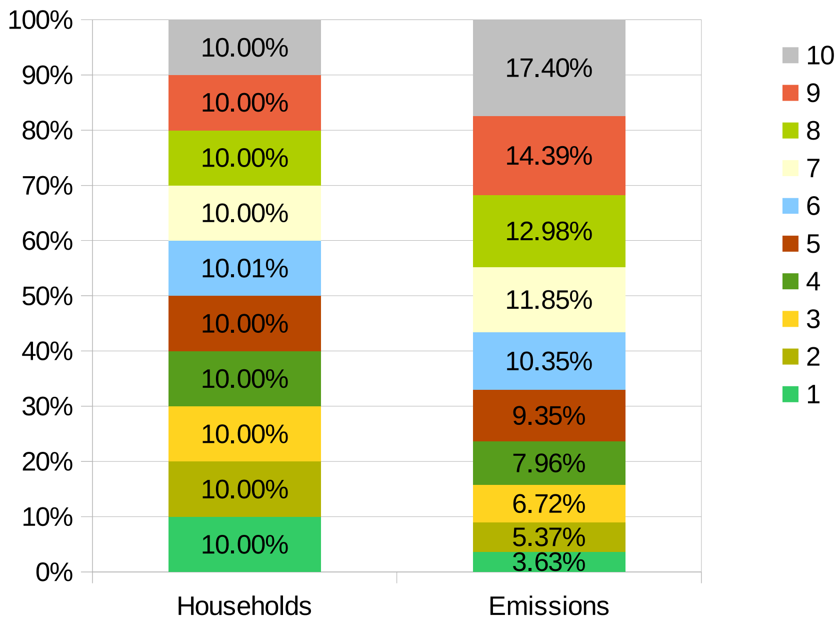

Figure 5: Share of households and share of household emissions by dispos. income deciles

5.2.2 Social status and emissions

Emissions show striking differences for households with different social statuses of the main income earner (MIE). Figure 6 shows that student and unemployed households have by far the lowest emissions. Farmers, followed by civil servants and formerly self-employed pensioners have the comparatively highest emissions.

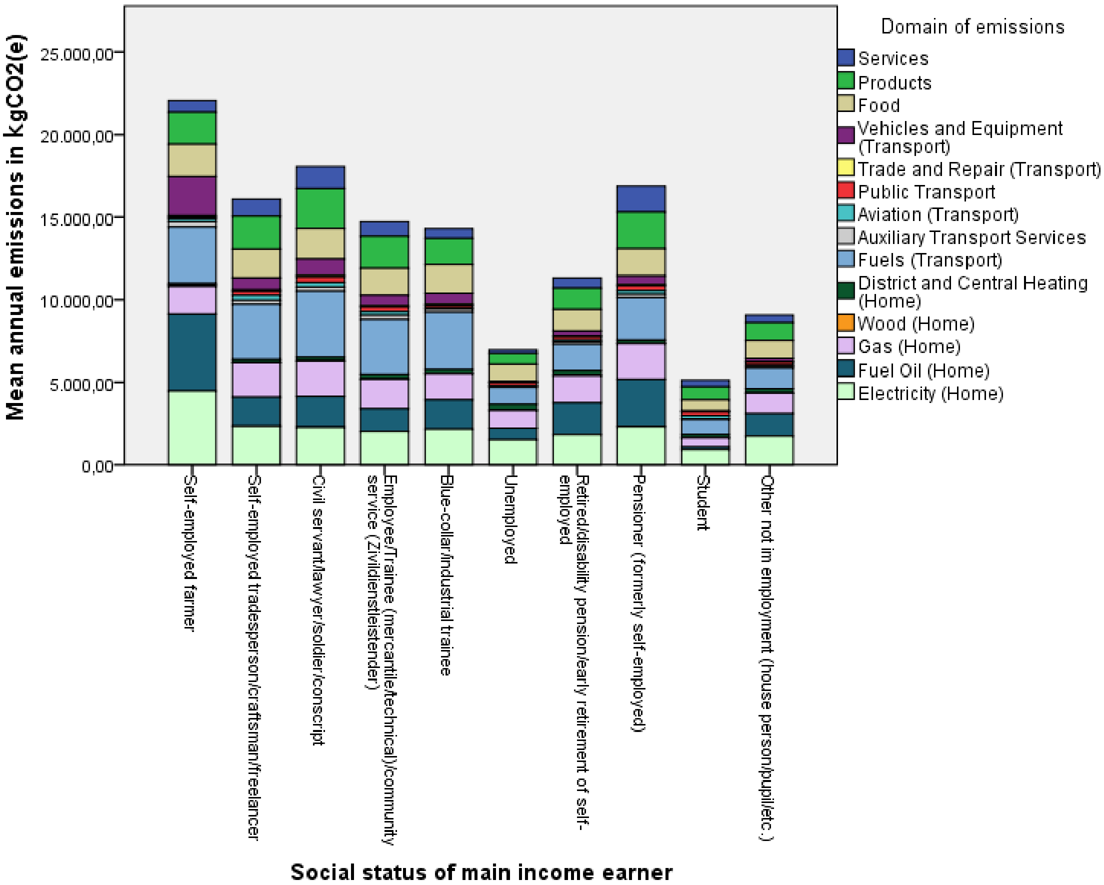

Figure 6: Emissions in kgCO2(e) of households with different social status of MIE

As we see in figure 7, the composition of emission varies visibly over social statuses. Students show the relatively highest share of emissions from public transport and aviation but barely heat their homes with fuel oil. Unemployed households have the relatively lowest share of emissions from products and services and the relatively highest share of emissions from direct energy (mostly home energy). Self-employed farmers show comparatively high emissions from fuel oil, electricity and vehicles/equipment. This could be explained by their often exposed and remote building structure and respective heating and home energy systems.

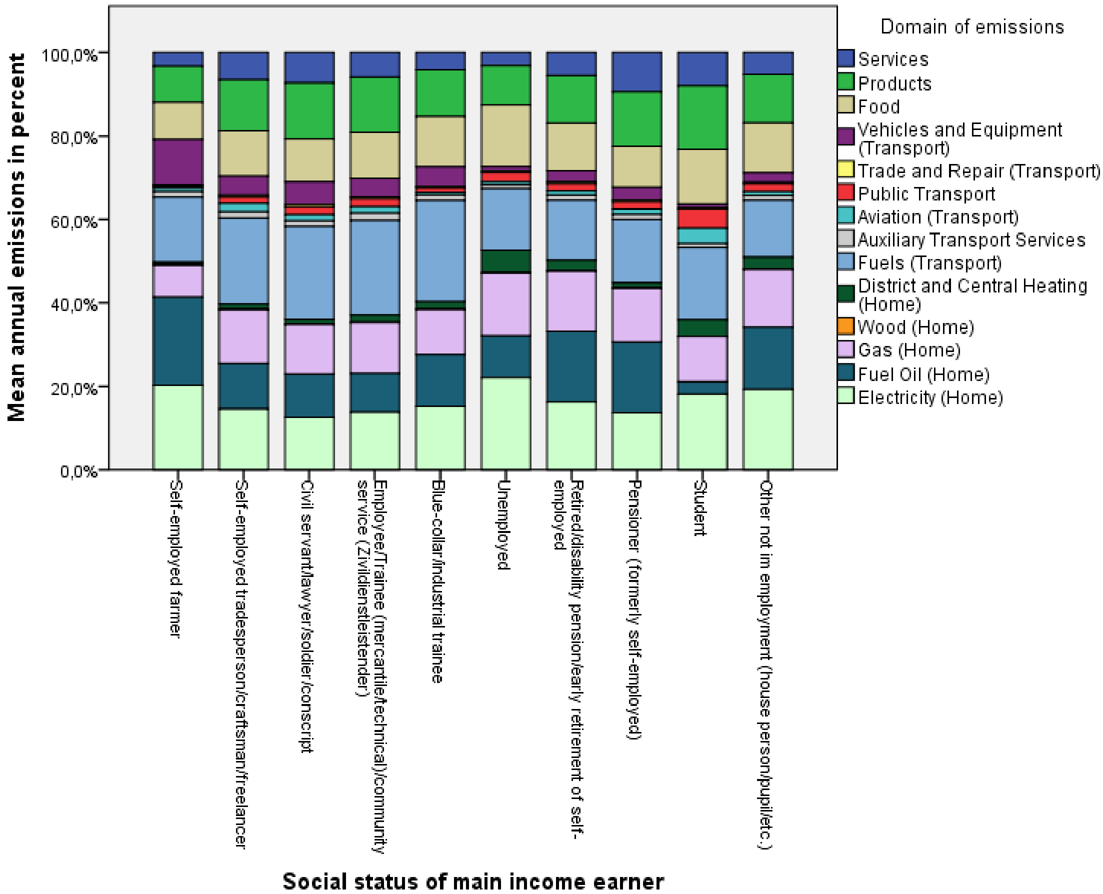

Figure 7: Emissions in percent of households with different social status of MIE

Looking at the relevance of each household type (figure 8) we find that self-employed farmers only constitute 0.21% of total households but 0.33% of total household emissions. White-collar employees (42.68% of emissions), households in retirement (19.7% of emissions) and civil servants in turn account for the bulk of emissions. Households with really low emissions, namely students, unemployed and others together account for as little as 3.52% of emissions. Strong correlations to low income obtrude themselves.

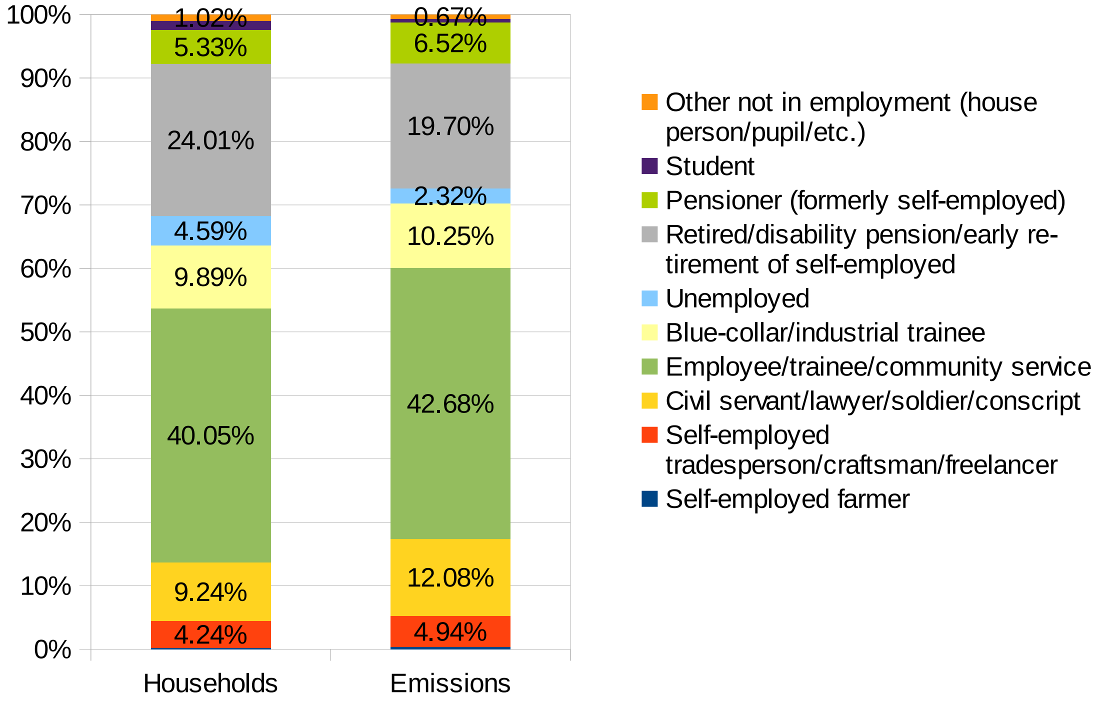

Figure 8: Share of households and share of household emissions by social status

5.2.3 Higher education, profession and emissions

Figure 9 shows associations between higher education, professional training and emissions. A household in which the MIE holds a PhD shows the comparatively highest mean emissions. Households in which the MIE has no job training and did not graduate have around half of the emissions of a household with a PhD. On average, academic households have higher emissions than households with a professional training (significant at the $p<0.05$ level). It remains to be answered whether the impact of education on emissions us significant after income is controlled for.

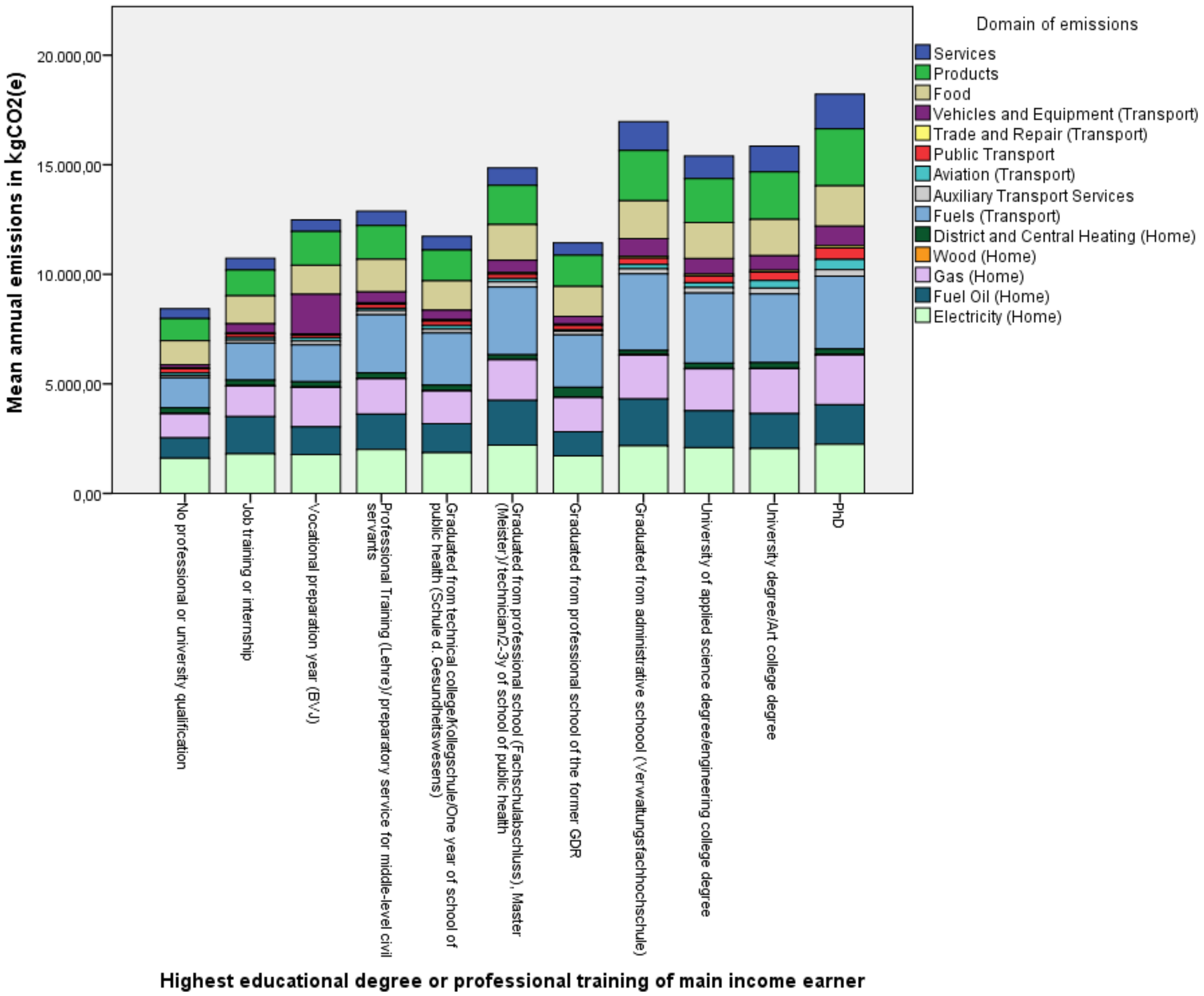

Figure 9: Emissions in kgCO2(e) of households with different educational and professional background of MIE

5.2.4 Age and emissions

With regards to age, two patterns are observable. Firstly, household emissions peak at the age of 50-54 years of the MIE. Afterwards, they steadily decline the older the MIE is. This inverse u-shaped relationship confirms previous findings by Büchs and Schnepf (2013a). Secondly, the share of emissions from home energy, especially heating fuels, increases in absolute terms steadily from the age of 30-34 to 58-59 and stagnates thereafter (figure 10).

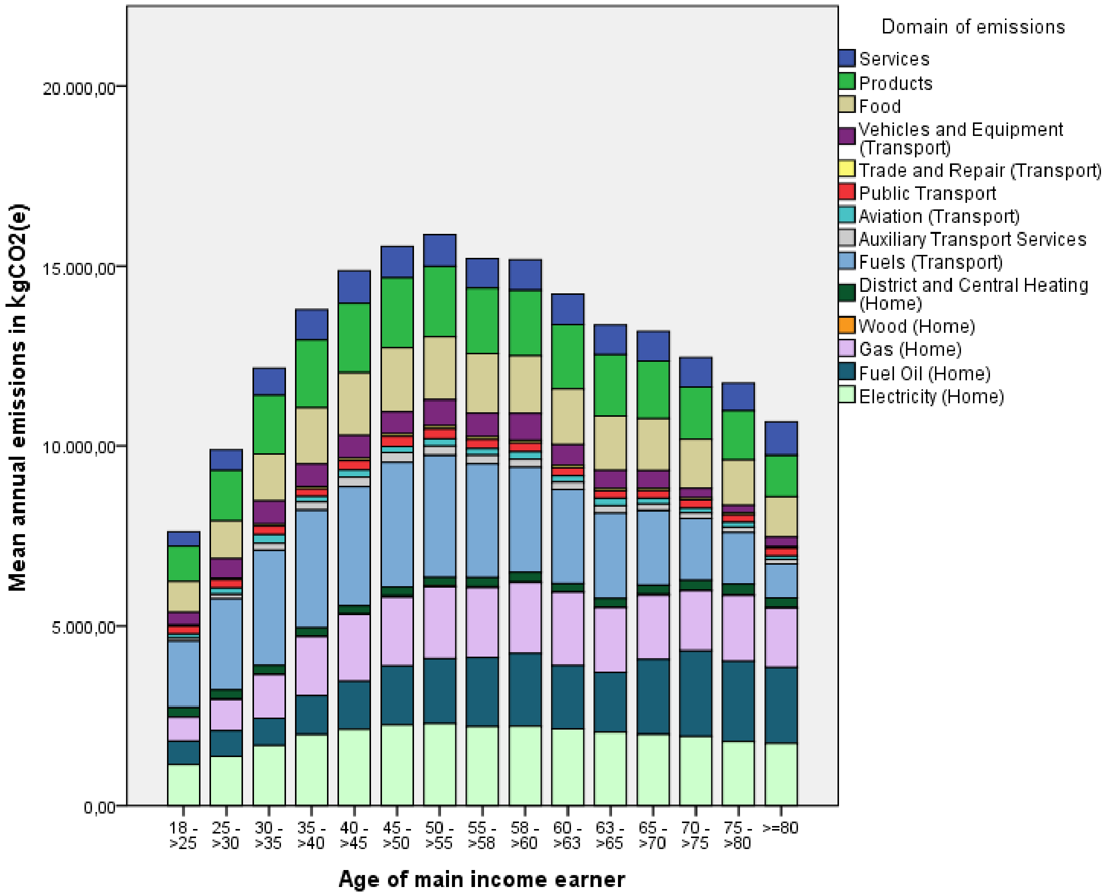

Figure 10: Emissions in kgCO2(e) of households with different age groups of MIE

5.3 Multivariate regression analysis

For the regression analysis, we first run a model with income and household size, differentiated between adults and children, as predictor variables (model 1). The R^2 values indicate how much of the variance in the dependent emissions variable are explained by the model. Secondly, a model which additionally includes a second set of predictor variables is tested (model 2). The results are presented in table 3.[6] The R^2 change values show how much explanatory value is added by including the second set of predictor variables into the regression.

6 All regression models are statistically significant at the $p< 0.0005$ level and meet the assumptions of homoscedasticity and linearity and multicollinearity. The normality of residuals as measured by kurtosis and skewness lies within the +/-2 range for total and home energy emissions. For indirect CO2 emissions, a slightly higher kurtosis of 2.5 and for transport emissions a kurtosis of 5.9 is calculated. Due to the very large sample size, this is however not considered a problem. The results of the analysis are therefore assumed to be robust. More detailed regression results can be requested from the authors.

	Total CO2 emissions 1)		Home energy CO2 emissions 2)		Transport CO2 emissions 3)		Indirect CO2 emissions 1)	
	B	β	B	β	B	β	B	β
Model 1	**// R² = 0.56**		**// R² = 0.182**		**// R² = 0.324**		**// R² = 0.558**	
Constant	2.857***		4.14***		-5.519***		0.772***	
Ln disposable income	0.532***	0.57	0.274***	0.227	1.269***	0.493	0.66***	0.631
Number of children	0.066***	0.092	0.083***	0.088	0.046***	0.023	0.061***	0.075
Number of adults	0.192***	0.227	0.244***	0.225	0.261***	0.113	0.142***	0.15
Model 2	**// R² = 0.583**		**//R² = 0.268**		**// R² = 0.370**		**// R² = 0.576**	
Constant	3.509***		5.22***		-3.597***		0.721***	
Ln disposable income	0.439***	0.471	0.098***	0.081	1.025***	0.398	0.659***	0.631
Number of children	0.049***	0.068	0.075***	0.079	-0.058***	-0.029	0.079***	0.098
Number of adults	0.142***	0.168	0.169***	0.155	0.14***	0.06	0.128***	0.135
Living area in sqm	0.002***	0.112	0.004***	0.239	0**	0.012	0***	-0.023
Rural (< 20000 inhabitants)	0.052***	0.044	0.036***	0.023	0.252***	0.076	-0.027***	-0.02
Federal city state	-0.05***	-0.024	-0.012	-0.004	-0.258***	-0.043	0.02**	0.008
East German state	-0.007	-0.005	-0.037***	-0.021	0.102***	0.026	-0.04***	-0.026
Construction year > 1991	-0.066***	-0.048	-0.13***	-0.073	-0.019	-0.005	-0.044***	-0.029
Married MIE	0.082***	0.07	0.056***	0.037	0.241***	0.073	0.109***	0.083
Accommodation owned	0.003	0.003	0.161***	0.106	0.003	0.001	-0.105***	-0.08
Accommodation free	-0.081***	-0.021	0.165***	0.03	-0.041	-0.004	-0.115***	-0.027
Edu introductory training	0.026*	0.007	-0.037	-0.007	0.22***	0.02	0.005	0.001
Edu professional training	0.051***	0.043	-0.016	-0.011	0.533***	0.16	0.031***	0.023
Edu graduated tech. college	0.028**	0.01	-0.037	-0.01	0.513***	0.065	0.031**	0.01
Edu graduated master (crafts)	0.06***	0.033	-0.049**	-0.021	0.626***	0.126	0.047***	0.023
Eud graduated GDR	0.032**	0.011	-0.029	-0.008	0.5***	0.63	0.035**	0.011
Edu graduated administrative	0.071***	0.023	-0.063**	-0.016	0.577***	0.069	0.086***	0.025
Edu graduated from uni	0.04***	0.031	-0.07***	-0.041	0.563***	0.154	0.081***	0.055
Edu PhD	0.03*	0.008	-0.094***	-0.019	0.47***	0.044	0.113***	0.026
SocStat self-employed farmer	-0.149***	-0.011	-0.086	-0.005	-0.332**	-0.009	0.017	0.001
SocStat self-employed	-0.02*	-0.007	0.042**	0.011	-0.232***	-0.029	-0.003	-0.001
SocStat employee (whitecollar)	-0.006	-0.005	-0.01	-0.006	-0.067***	-0.02	0.029***	0.022
SocStat civil_servant	0.022**	0.011	0.006	0.002	-0.05	-0.009	0.073***	0.032
SocStat retired	-0.028	-0.02	0.059***	0.033	-0.428***	-0.113	-0.002	-0.001
SocStats pensioner (self-empl)	0.007	0.003	0.069***	0.02	-0.358***	-0.05	0.076***	0.026
SocStat student	-0.179***	-0.037	-0.121***	-0.018	-0.477***	-0.035	0.137***	0.026
SocStat unemployed	-0.092***	-0.037	0.077***	0.024	-0.781***	-0.111	-0.073***	-0.026
Female	0.018***	0.015	0.043***	0.027	-0.034**	-0.01	0.038***	0.028
Age 18-24	-0.06***	-0.014	-0.088***	-0.015	0.211***	0.018	-0.006	-0.001
Age 25-29	-0.017	-0.006	-0.064***	-0.018	0.094***	0.012	0.013	0.004
Age 40-49	0.001	0.001	0.069***	0.04	-0.117***	-0.032	0.018**	0.012
Age 50-59	0.011*	0.008	0.117***	0.063	-0.203***	-0.051	0.028***	0.017
Age 60-63	0.034***	0.014	0.126***	0.039	-0.149***	-0.021	0.081***	0.029
Age 64-75	-0.008	-0.006	0.078***	0.041	-0.131***	-0.032	0.087***	0.053
Age 76 +	-0.091***	-0.037	0.091***	0.029	-0.665***	-0.097	0.024	0.009
From model 1 to model 2:	**// R² change: 0.023**		**// R² change: 0.086**		**// R² change: 0.047**		**// R² change: 0.018**	

*** $p < 0.01$
** $p < 0.05$
* $p < 0.1$

1) N: 39867. Outliers filter: CO2_total < 7788g per quarter, based upon Stem-and-Leaf plot for CO2_total
2) N: 39059. Outliers filter: ln_CO2_home > 4.7 & ln_CO2_home < 9.1, based upon Stem-and-Leaf plot for ln_CO2_home
3) N: 42260. Outliers filter: none

Table 3: Multivariate hierarchical regression results for total, indirect, transport and home energy CO2 emissions

The regression results mostly confirm the assumptions. We find that income and household size are the main drivers for total and indirect household emissions. The more income a household has at its disposal, the higher its carbon footprint. The more members a household has, the higher are its emissions. Per capita emissions in larger households on the other hand decrease significantly due to the economies of scale. Income and household size prove to be the key predictor variables and generate models with a good fit (total emissions: $R^2 = 0.56$; indirect emissions: $R^2 = 0.558$). The second set of predictor variables increases the explained variation of total emissions by only 2.3% to 58.3% (model 2). For indirect emissions, R^2 changes similarly marginal by 0.18 to an R^2 value of 0.576 in model 2. For total and indirect emissions, the explanatory value added by other socio-economic factors than income and household size is relatively small.

For home energy emissions, income and household size alone explain a relatively small amount of variance of emissions ($R^2 = 0.182$). Here, the living space in m² is, according to the standardised coefficient, a more important driver of emissions than income. Home energy emissions are also significantly increased by home ownership, number of adults and a high age of the MIE once all other factors are controlled for. Additional socio economic factors increase the explanatory value significantly to $R^2 = 0.268$ (model 2).

For transport emissions, higher education, income and rural dwelling are the most important emission drivers. Further important drivers include marriage of the MIE and the number of adults in the household. Here, income and household size explain 32.4% of emission variance while other socio economic factors increase the explanatory value of the model by 4.6% to 37%.

The regression results show that many socio-economic factors remain significant once income and household size are controlled for. With regards to total emissions, especially living area in m², rural dwelling and professional training are important additional drivers of emissions. Surprisingly, education (e.g. a university degree), female gender and marriage are also found to be significant drivers of total emissions.

The analysis proves that associations between socio-economic factors and emission vary for different emission types. In these respects, the results are very similar to previous analysis for the UK (Büchs and Schnepf, 2013a).

For total emissions, reducing factors are the residing in a building constructed after 1991, being a student or unemployed as well as high age of MIE (above 76). Surprisingly, self-employed farmers also have lower total emissions than blue-collar households once all other factors are controlled for.

6. Summary of findings

The analysis shows that emissions are highly concentrated on a consumption basis – few households emit significantly more CO_2 than others. Especially emissions from home energy and transport are concentrated towards high emitters.

The descriptive analysis finds that emissions are very unevenly distributed over different types of household. Significant differences exist with regard to income, gender, social status, age and educational/professional background, of the MIE as well as the household type, number of children, renting/ownership, construction year of the building, spatial location and federal state of the household. Households from the highest income decile for instance emit almost five times as much CO2 as households from the lowest income decile. Students and unemployed households emit significantly less than households from all other social statuses and already have a rather sustainable carbon footprint.

The regression results show that income and household size are the most important factors to predict total and indirect emissions. A whole range of further socio-economic factors is significantly influencing emissions once income and household size are controlled for. For home energy emissions, living space in m² and household size are the most important drivers. For transport emissions, income, higher education and rural dwelling are the most important drivers.

There are problems with the EE IO model used for this analysis that also affect the results (see chapter 4). Therefore, trade-embodied emissions and indirect household emissions are significantly under-estimated. The validity of results is thus limited to the extend that average household emissions are presumably lower according to our results than in reality. Despite the model limitations, the analysis follows a proven method for assessing the distribution of household emissions and especially the results for home energy and transport emissions are robust. The implications for future policies aiming at emission reductions from consumers, including degrowth strategies, are discussed in the following.

7. Policy implications

As outlined in chapter 2, successful climate mitigation requires new policies aiming at the consumption side of emissions (Anderson and Bows-Larkin, 2013; Barrett, 2013; Helm, 2012a; Hertwich and Peters, 2009).

Various options have been discussed. Helm (2012a, 2012b) for instance advocates a shift to taxation of carbon consumption, including border tax adjustments to account for carbon embodied in traded goods and services. Fawcett (2012) prioritises the introduction of a Personal Carbon Trading Scheme (PTC). PCT schemes have been promoted for their progressive distributional effects. Anderson and Bows-Larkin (2013) conclude that only a temporary degrowth strategy of developed countries such as Germany would be a viable solution to mitigate dangerous climate change beyond 2°C.

From a consumption perspective, households are the main CO2-source. Therefore, households will have to play a major role in future mitigation policy. To achieve emission reductions effectively it is possible to tailor such policies. This also appears relevant since any current mitigation policies have been heavily criticised for their unfair distributional effects. Policies such as the Renewable Energy Act (EEG) often show regressive effects – implying that low-income households are generally worse off than wealthier households. Many mitigation policies are often also unfair with regards to other socio-economic criteria such as age (e.g. Büchs et al., 2011). The results of this analysis allow a glimpse about who would be affected most by mitigation measures with a financial lever.

The pledges of the Copenhagen Accord call for emission reductions “on the basis of equity” (UNFCCC, 2009:2). While it is ultimately the political process which determines where emissions are reduced and which principle is applied, equity has to be considered as an important factor, e.g. for public acceptability. Several mitigation principles have been discussed in the literature.

7.1. The polluter pays principle

In international climate policy, especially the polluter pays principle gained recognition as a principle of allocating costs to polluting entities (Biermann et al., 2003). The polluter pays principle can be defined as “the commonly accepted practice that those who produce pollution should bear the costs of managing it to prevent damage to human health or the environment” (Grantham Research Institute and Clark, 2012). Under this principle, a nuclear power operator could be held accountable for the safe storage of the produced nuclear waste or a dirty coal power plant for the mitigation of pollution caused. Taxing CO2 and other GHG is a popular way of enforcing the principle for the case of GHG mitigation (ibid.).

Applied downstream at the consuming entities, the polluter pays principle implies that households which pollute high amounts of emissions should bear the respectively appropriate costs for mitigation. A household with a sustainable lifestyle on the other hand should have to pay comparatively less under the principle (Pye et al., 2008:25).

The polluter pays principle is neither the only approach to allocate emission rights nor necessarily the preferred. Further principles include the equal share principal, the victim pays principle and the capacity of cost bearing (Büchs and Schnepf, 2013a:119; Biermann et al., 2003:3).[7] Some debates address emission needs and respective distribution of emission grants (Büchs and Schnepf, 2013:119).

7 Strong exemptions of many energy-intensive industries from paying for ETS allowances or the EEG surcharge show that often contradicting rationales come into play (Meyer-Ohlendorf and Blobel, 2008:119).

Our analysis has shown that emissions are rather skewed towards high-emitting households. Around 20% of households cause 40% of total emissions. For transport and home energy, emissions are even more concentrated. Here, 20% of households cause nearly 50% of emissions. On the bottom end, 50% of households are responsible for as little as 20% of emissions from these domains.

Polices tailored at high emitters could induce significant emission reductions. Anderson concludes that only a small minority of very high emitters would need to radically mitigate. (Anderson, 2013:106 ff.). Large shares of households on the other hand could remain more or less exempted from strong changes.

7.2. Socio-economic information and emission reductions

The information about socio-economic factors and their associations with emissions can not only be used to avoid negative distributional effects, it can also be used to identify emission reduction levers. In sum, a broad range of different measures exists to reduce the footprint of households. Income as a key driver for emissions plays a dominant role. Hence, progressive carbon pricing could be a relatively equitable option in accordance with the polluter pays principle as long as the emission dispersion within income groups is further accounted for.

Since household size, living space in m² and spatial location are further important drivers for total emissions, it makes – from a climate perspective – sense to incentivise smaller living spaces, shared accommodation and urban dwelling. There are obvious limits to these levers, though. Not everybody can or should for instance move to the cities where the average carbon footprint is statistically smaller. In this case, better countryside infrastructure, for instance a sustainable public transport network, could be a more applicable solution.

Where influencing socio-economic factors is no feasible or plausible option, e.g. for age, more underlying societal aspects and contexts should be considered. Elderly inhabitants have higher heating requirements to achieve a more comfortable living environment. Therefore, energy efficiency measures, e.g. better insulation, could be particularly effective for this group.

The widely shared hope that better education induces environmentally friendly acting is not supported by our data. In fact, education appears as a significant driver of emissions, especially from the transport sector. This imposes a considerable challenge to policy makers.

Already existing mitigation measures, e.g. electricity saving checks for low-income households

(Stromsparchecks in Germany) are – from a climate perspective – rather misleading due to the fact that unemployed and low-income households – as well as student households – already have the comparatively sustainable carbon footprint. Based on our results, energy saving checks for wealthy/high emission households would be a far more effective measure – at least as long as rebound effects remain neglected.

7.3. Decarbonisation or degrowth?

The question as to whether decarbonisation measures aiming at emission reductions from household consumption lead to the required reductions to avoid exceeding 2°C or whether degrowth strategy as advocated by Anderson and Bows-Larkin (2013) would be required cannot be answered on the basis of our data. Yet, there are certain limitations to the decarbonisation of household consumption which can be highlighted.

Generally there are two different ways to reduce the carbon footprint of a household. The first option is to reduce the carbon intensity of a sector, e.g. of transport. However, this option has to be considered as a mostly exogenous variable as it implies changes on the production side. We have already argued in the beginning of this paper that the current decarbonisation rate of sectors on the production side is too slow to reduce emissions to sustainable levels. Nevertheless, consumers and consumer choices can increase the pressure to decarbonise faster, e.g. by purchasing more sustainable organic food instead of non-organic products.

The second option is to reduce emissions by shifting household consumption towards sectors with lower CO2 intensity (e.g. from transport to services). This reduces a household's average CO2-emissions per € of expenditure and thereby its overall footprint. However, this approach is limited as there is is no full exchangebility between the different consumption sectors in reality. Food for instance cannot be fully substituted below a certain level by a lower carbon-intensive sector. The same accounts for home energy, mobility, products and all other sectors. At least certain basic needs or preferences (whatever these might be) would have to be satisfied.

Moreover, every expenditure in sector A also leads to certain emissions in other sectors. Going to the cinema (service) also requires a certain amount of transport energy, unless the cinema is within walking distance. The reduction of the average carbon intensity of a household is limited to the extend that the domains of consumption are interconnected and not fully exchangeable.

As mentioned, the reduction of a household's average carbon intensity appears only possible for every Euro spent which exceeds the demand for certain basic needs/preferences. For households with a small carbon footprint (e.g. low-income households, students or unemployed), this very much limits the possibilities to decarbonise. Low-emitting households either already have low expenditures (which is strongly associated with a low income) or a low average carbon intensity (or both, respectively). Mitigation policy aiming at household consumption therefore will not (in case the household has a low average carbon intensity anyway) or should not (a high average carbon intensity of a low-emitting household's indicates that the household is extremely poor) affect these households in order to maintain the fulfilment of certain basic needs. The opposite is the case for high polluters. A discussion about what basic needs of emissions are is all the more important.

An alternative degrowth way to lower emissions could be a reduction of household expenditure, e.g. through an abstention from consumption. This is certainly a highly disputed option with consequences for the overall economic system. However, the general implications from our analysis would be the same as for the decarbonisation option. The results suggest that in a degrowth economy, not every household has to equally reduce its emissions to a sustainable level. If the decarbonisation option fails to reduce emissions sufficiently, a degrowth option could theoretically deliver emission reductions in accordance with the polluter pays principle (if the key socio-economic drivers of emissions were considered). Undoubtedly, a reduction of household expenditure by high-emitters (which are often also high-earners) is not a quite realistic option.

Whether decarbonisation or degrowth, recognising the distribution and drivers of emissions could potentially guide for more equitable policy measures aiming at emission reductions on the consumption side. Anderson concludes that only a small minority of very high emitters would need to radically mitigate. Polices tailored at high emitters could induce significant emission reductions (Anderson, 2013:106 ff.). Large shares of households on the other hand could remain more or less exempted from considerable changes. The devastating consequences of climate change on the other hand would have to be borne by everyone.

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