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The distribution and drivers of CO_2 emissions on a consumption basis and implications for a degrowth economy – the case of Germany

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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 last year in Warsaw, 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 its 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 remain within the 2°C threshold after which climate change becomes uncontrollable and extremely dangerous, CO2 emissions have to remain within the range of around 1.000 Gt (Carrington and Vidal, 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

1 Compared to 1986–2005 levels.
2 Between 820-880 GtCO2 if other greenhouse gases are accounted for (Carrington and Vidal, 2013).

intensity of the global economy until 2100 would be required (PwC 2013). Anderson and Bows-Larkin (2011; 2013) calculate that for Annex I countries, a reduction rate of unprecedented 8-10% p.a. would be necessary.

The majority of policy measures in industrialised countries, including Germany, have thus far 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 of 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 sustainable footprint.

Despite the relevance of household emissions, the knowledge of how emissions are distributed over households is still limited, also due to methodological and data limitations (Gough et al., 2011). No previous study exists for Germany, the largest emitter within the EU. Based on a MSc dissertation at the University of Sussex, this paper addresses the research gap by answering the questions of how emissions are distributed over different household types in Germany and what the socio-economic drivers of emissions are. Furthermore the implications for a degrowth economy are discussed.

2. Shifting the focus on carbon consumption

The observable mitigation success of most Annex B countries, including Germany, only holds true from a territorial accounting perspective. Looking at emission from a consumption perspective however, the picture looks quite different. Large shares of emissions were outsourced to emerging economies. 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., 2011b:1).

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

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 underpins the need for further policy action on the consumption side as advocated by various climate scientists (Anderson and Bows-Larkin, 2013; Barrett, 2013; Helm, 2012a; Hertwich and Peters, 2009).

Helm (2012a, 2012b) for instance advocates a radical shift to taxation of carbon consumption, including border tax adjustments to account for carbon embodied in traded goods and services. Fawcett (2012) suggests the introduction of a personal carbon trading (PCT) to induce emission reductions on the consumption side. Anderson and Bows-Larkin (2013) conclude that only a temporary de-growth strategy of developed countries such as Germany is a viable solution to mitigate dangerous climate change beyond 2°C.

3. Household consumption and the polluter pays principle

On a consumption basis, households are the main contributors to climate change. Energy and associated emissions ultimately serve and fulfil the needs of final consumers (Hertwich and Peters, 2009). Houshold 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. The distribution of emissions also has an intrinsic equity aspect which may allow to make inferences regarding different reduction potentials of different consumers.

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.). The question of who has to bear the mitigation costs is, however, highly debated. Several mitigation principles have been discussed and it is clearly not just an ethical but also a highly political debate. 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.

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 principal is neither the only approach to allocate emission rights nor necessarily the preferred. Other 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).[3] Some debates address emission needs and respective distribution of emission grants (Büchs and Schnepf, 2013:119).

4. Literature review

Previous literature on the distribution of emissions largely focuses on other OECD countries, predominantly the UK. Earlier work has focused on the analysis of the distribution 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).

According to Schoer et al. (2006:2), environmental pollution is not only influenced by personal behaviour but also 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).

4.1 The distribution of household emissions

Both direct and indirect emissions are unequally distributed over households (Gough et al., 2011:40; Büchs and Schnepf 2013a; Druckman and Jackson, 2009; Chitnis et al. 2013, submitted). Druckman and Jackson (2009) e.g. find above-mean emissions for households from prospering suburbs and the countryside and below-mean emissions e.g. for multicultural and urban households.

Income and household size are often assumed to be the main factors influencing household

3 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).

emissions. However, a broad range of other potentially influential factors including age, household type, social status, education, spatial location have controversially been discussed in the literature with regards to their associations to emissions (Büchs and Schnepf, 2013a:115).

Büchs and Schnepf (2013a:118) show that emissions from some consumption domains areas are more skewed than others. While the median of flights is as much as 1.13 tCO2 per household, almost 60% of the households did not fly at all in during the survey period.

An important finding from literature is that association between socio-economic factors and emissions are not equal for different types of emissions. Weber and Perrels (2000) find that especially transport emissions and home energy emissions show a large dispersion over different household types. Young singles and couples for instance show significantly higher transport emissions than elderly singles and couples. Emissions embodied in clothes on the other hand are more equally distributed.

The theoretical – and previously assessed – relationship between key socio-economic factors and GHG emissions are briefly summarised in the following.

4.2. Socio-economic factors

The compilation below is largely based on Büchs and Schnepf (2013a) and Gough et al. (2011) who summarised the most relevant debates around socio-economic drivers of emissions.

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 as indicated by Gough et al.

(2011:20) shows that other factors beyond income influence the distribution.

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 decrease 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 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.

5. Methodology

The analysis maps the CO2 intensity (kgCO2/€ of expenditure) derived from an environmentally extended input-output model (EE IO) and seperate calculations for home energy against the expenditure categories of the EVS 2008 household expenditure survey (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).

Mayer and Flachmann 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 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.

5.1 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 the updated data for 2008 by Mayer and Flachmann (2013), the CO2 intensities (kgCO2/€) are calculated on the basis of private household expenditure and consumption-embodied CO2. This provides us with a total of 25 different CO2 coefficients.

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

To achieve more accurate results, we conduct seperate calculations for home energy emission intensities 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 provides us with the average CO2(e) intensity in kgCO2(e) per € of expenditure (see table 1). Since some external sources provide the CO2e values per kWh, we display CO2(e) in the later analysis.

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

Source: Own calculations.

5.2 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 grateful to the Environmental Policy Research Centre at the Free University of Berlin for enabling the data access.

This dissertation 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.[4]

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

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

less prevalent, though.

5.3 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).

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 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. Full re-classification methodological details can be requested from the authors of this paper.

5.4 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 m² 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€.

6. 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 as described in chapter 5.

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.

6.1 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).

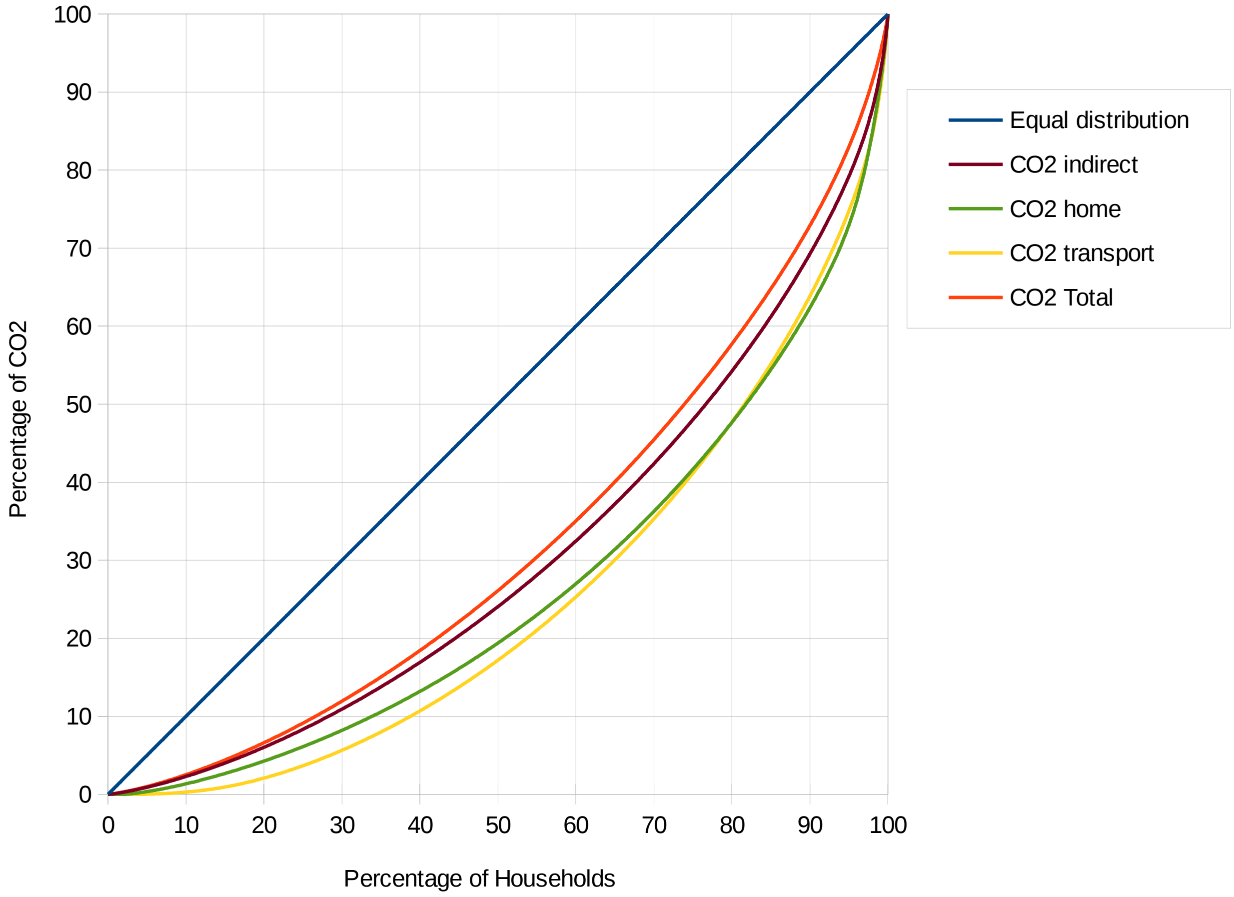

Figure 1: Lorenz curves of household CO2 emissions

The concentration of emissions has been calculated and visualised by using Lorenz curves (figure 1). 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.

6.2 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.

6.1.1 Income and emissions

Figure 2 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.

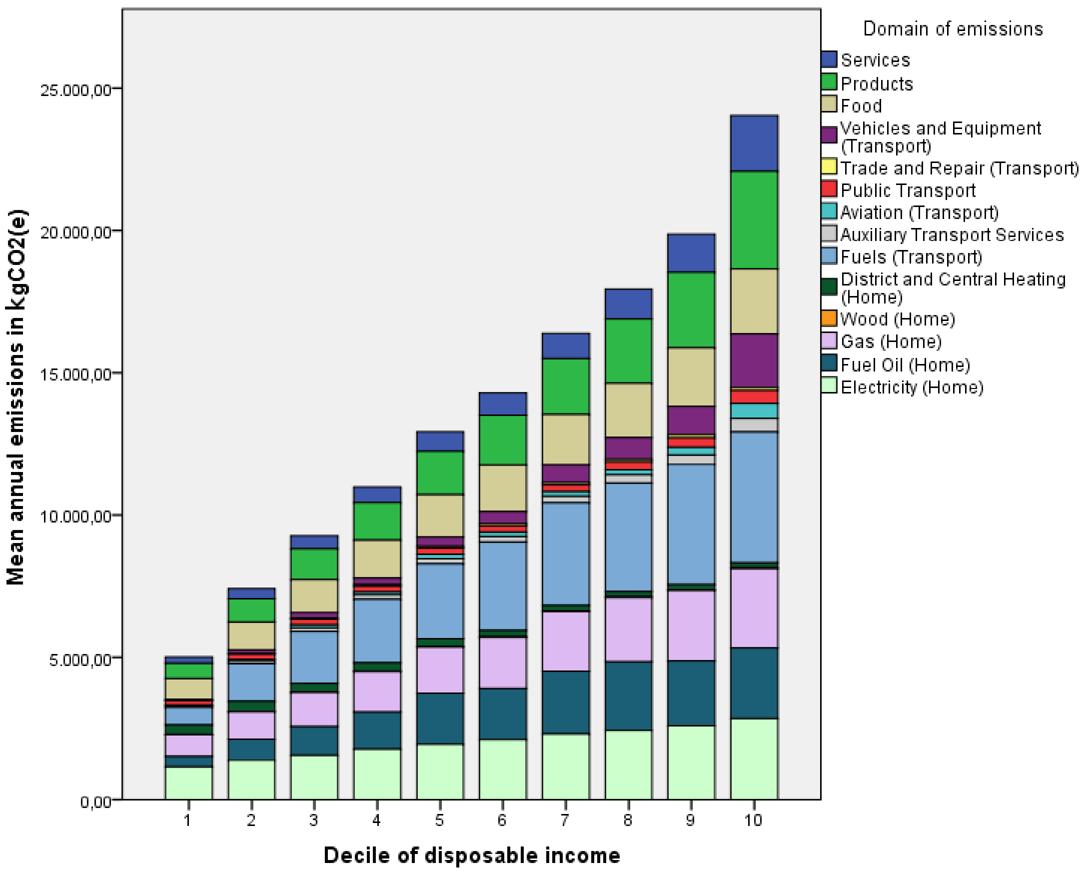

Figure 2: Emissions in kgCO2(e) of different disposable income deciles of households

Figure 3 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 10 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.

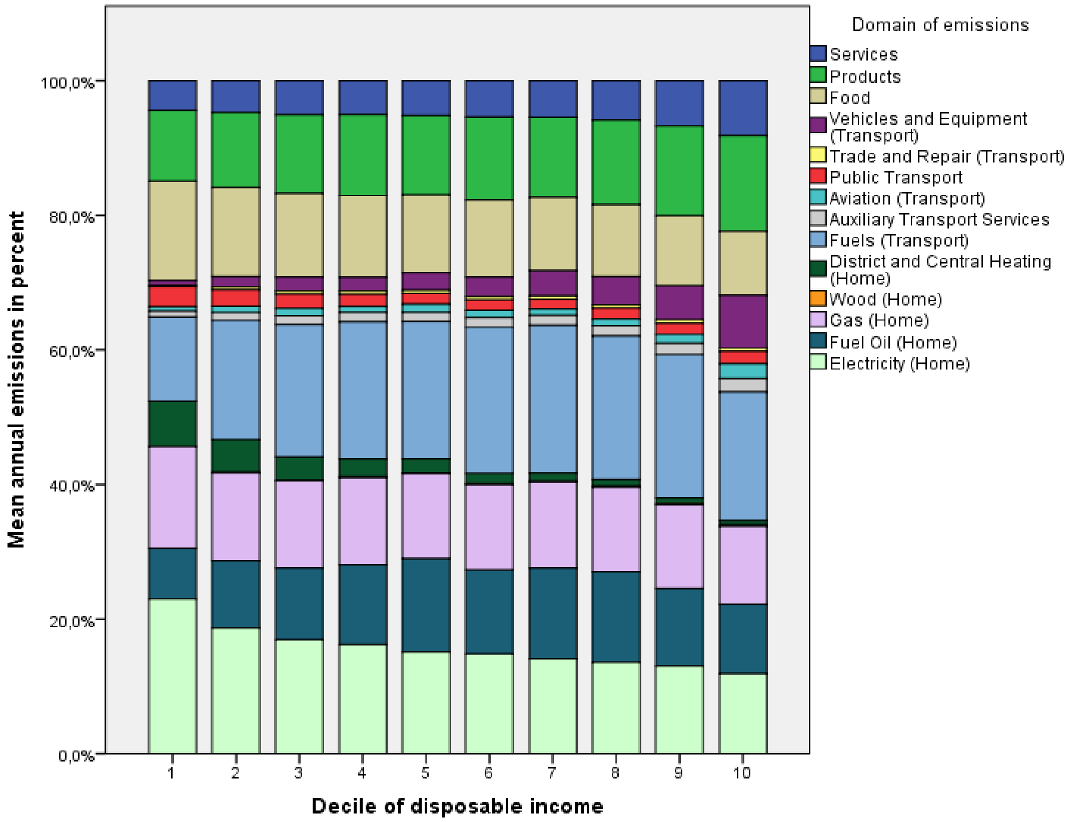

Figure 3: Emissions in percent of different disposable income deciles of households

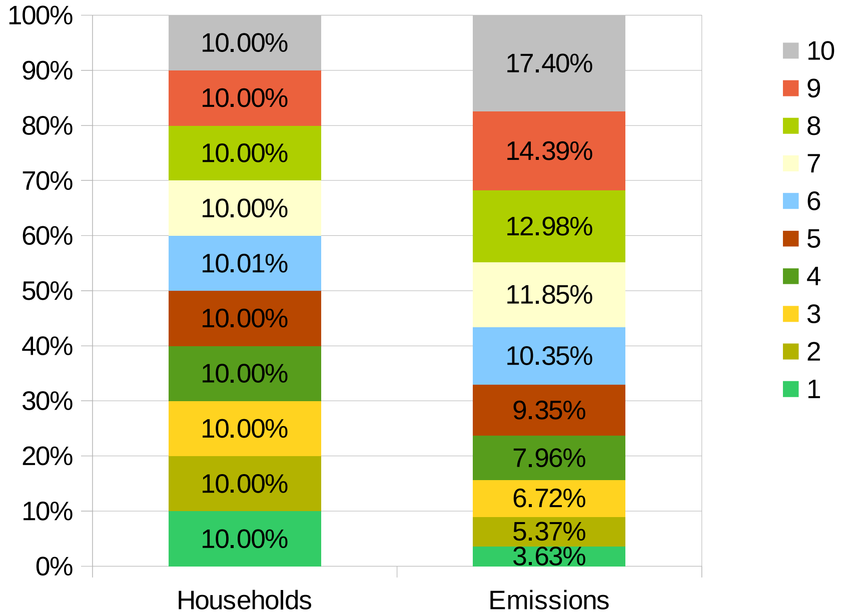

Figure 4: Share of households and share of household emissions by dispos. income deciles

6.1.2 Social status and emissions

Emissions show striking differences for households with different social statuses of the main income earner (MIE). Figure 5 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.

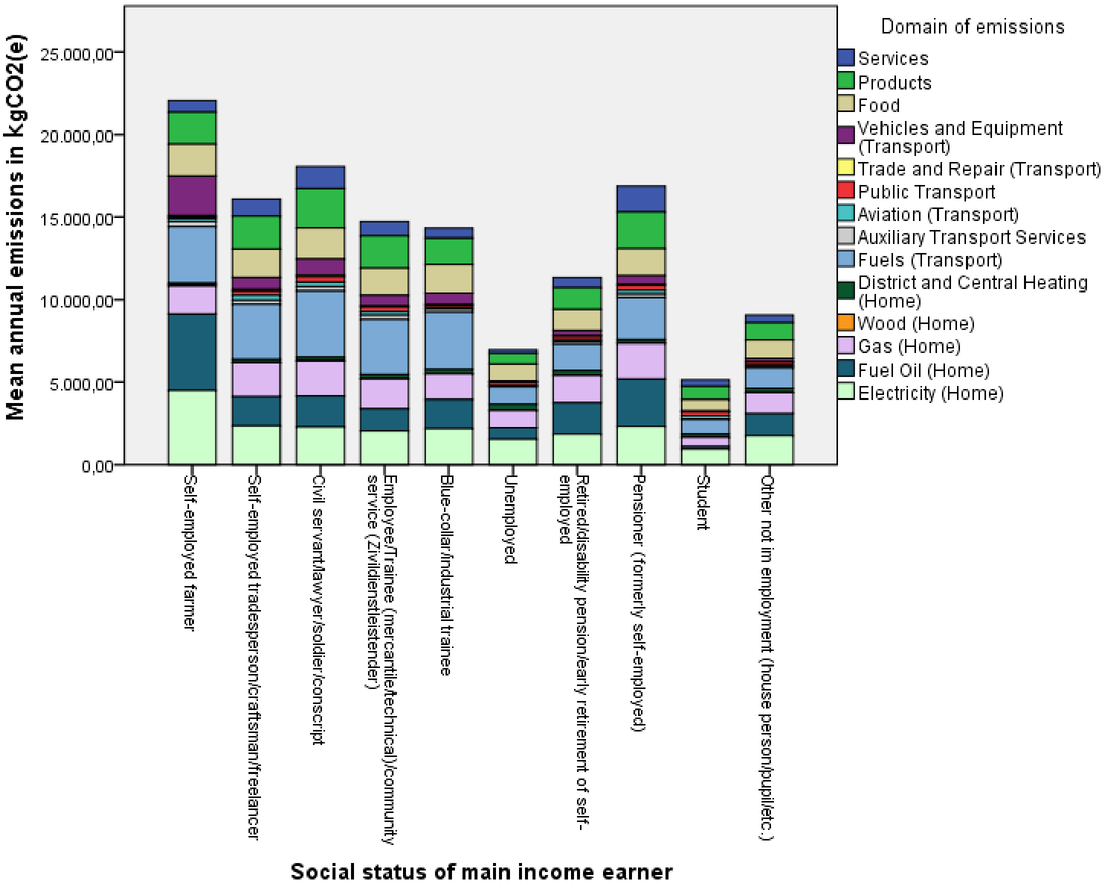

Figure 5: Emissions in kgCO2(e) of households with different social status of MIE

As we see in figure 6, 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.

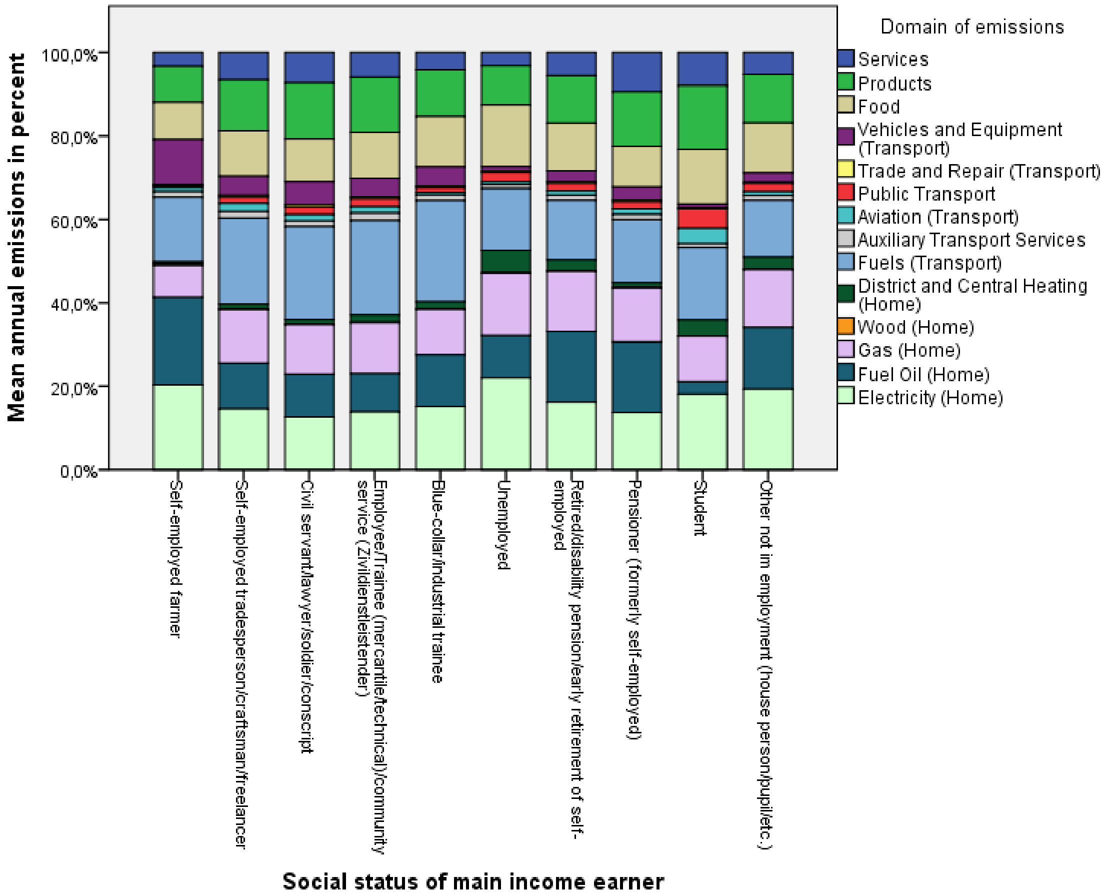

Figure 6: Emissions in percent of households with different social status of MIE

Looking at the relevance of each household type 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.

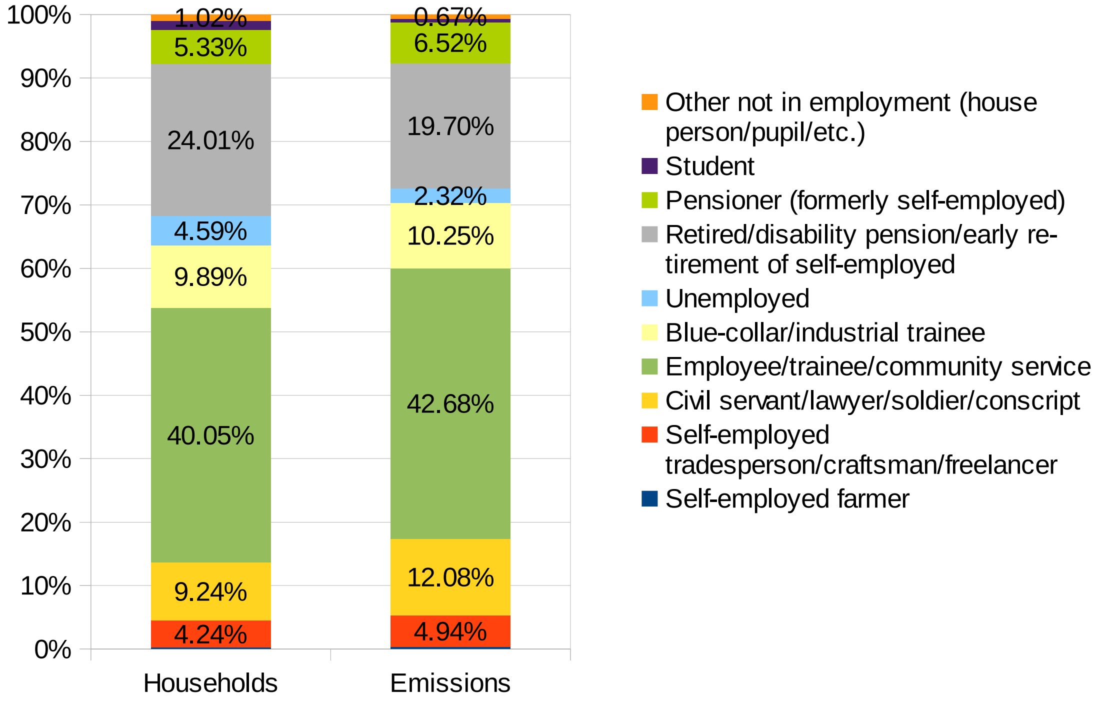

Figure 7: Share of households and share of household emissions by social status

6.1.3 Higher education, profession and emissions

Figure 8 shows associations between further education after school, 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.

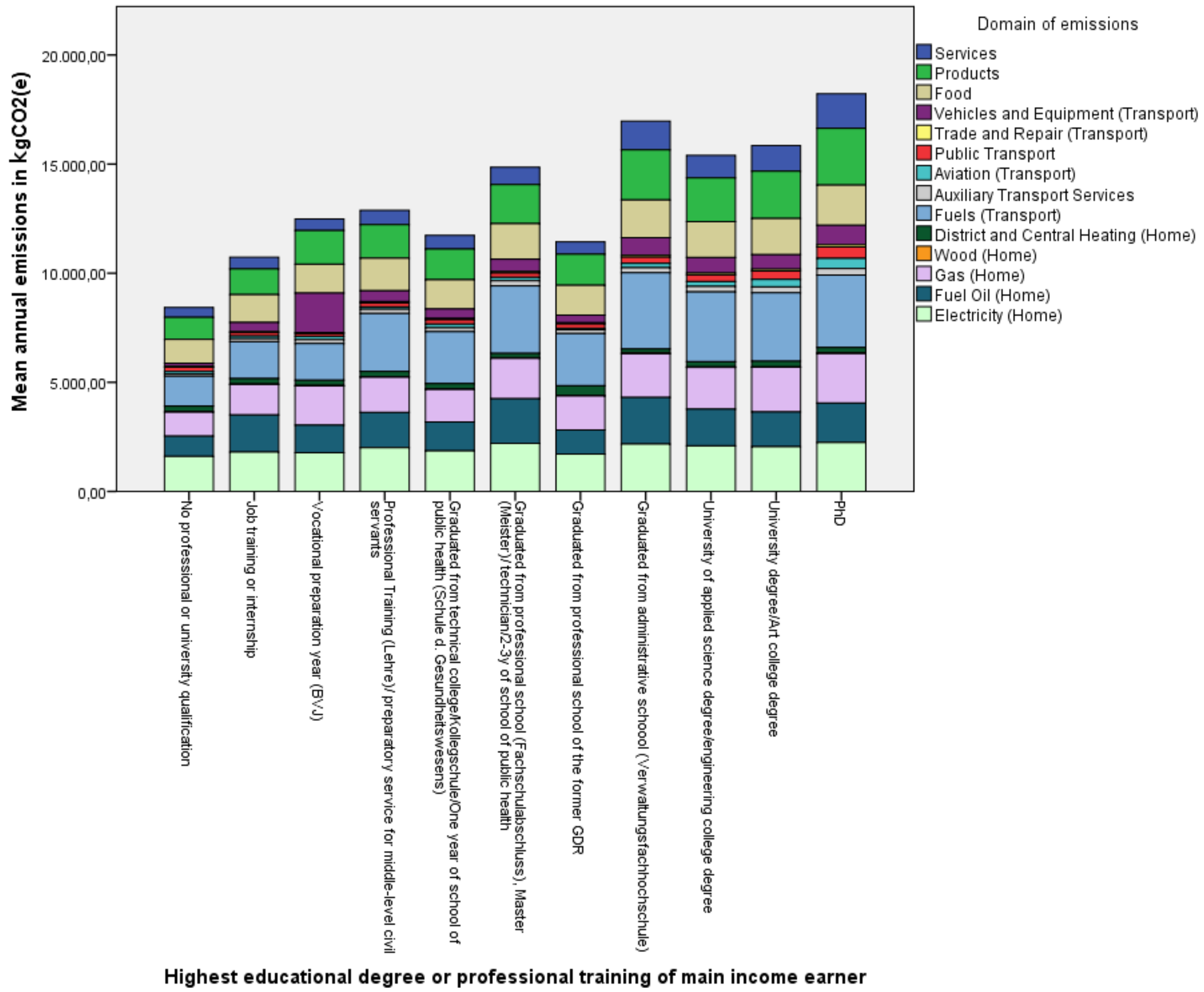

Figure 8: Emissions in kgCO2(e) of households with different educational and professional background of MIE

6.1.4 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 27).

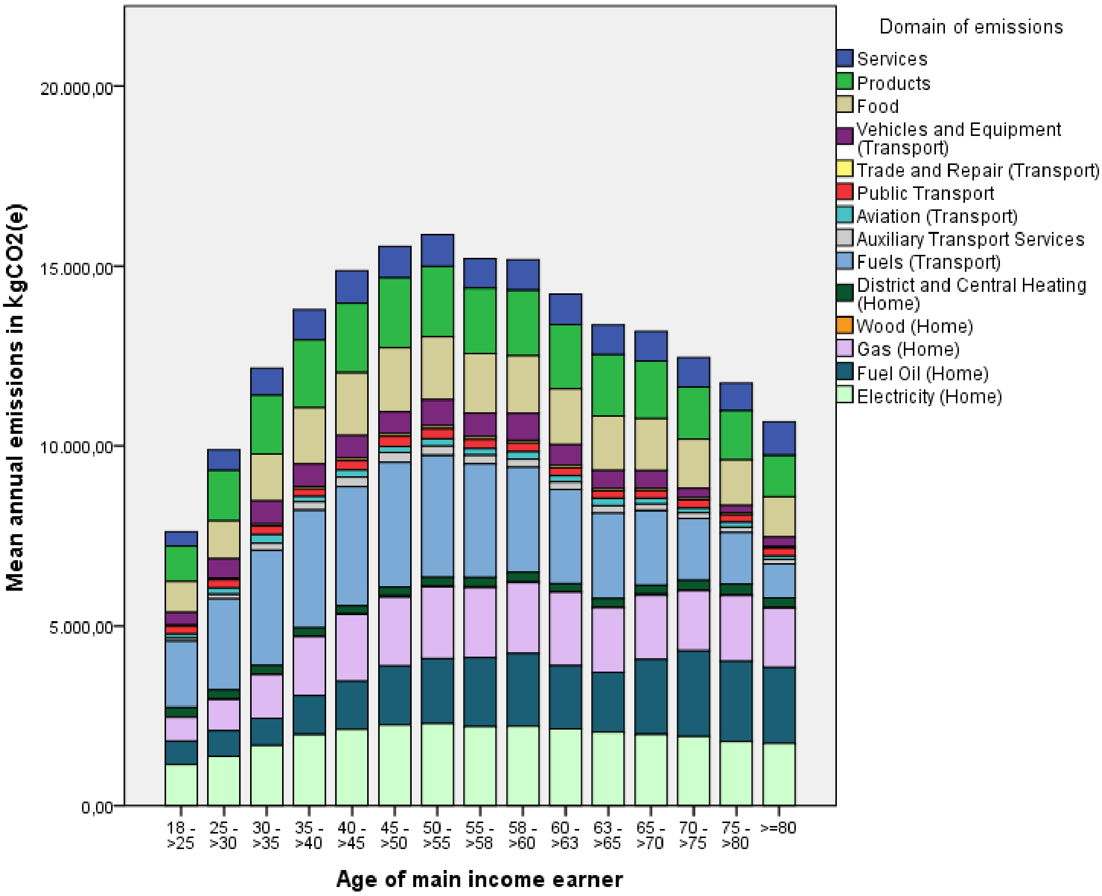

Figure 9: Emissions in kgCO2(e) of households with different age groups of MIE

6.2 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 2.[5] The R^2 change values show how much explanatory value is added by including the second set of predictor variables into the regression.

5 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 2: Multivariate hierarchical regression results for total, indirect, transport and home energy CO2 emissions

The regression results mostly confirm the hypotheses. 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 rural dwelling 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.

7. 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 highly concentrated.

The descriptive analysis finds that emissions are very unevenly distributed over different household types. 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.

The regression results show that income and household size are the most important factors to predict total and indirect emissions. A range of further socio-economic factors is significantly influencing emissions once income and household size are controlled for. Some socio-economic factors are highly important predictors for home energy and transport emissions.

There are problems with the EE IO model used for this analysis which affect the results (see chapter 5). Trade-embodied emissions and indirect household emissions are strongly under-estimated. The validity of results is therefore 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 a degrowth economy are discussed in the following

8. Implications of the analyses

Summary:

Before discussing the implications of our analysis for a degrowth economy, a brief summary of the paper's main content is given. The consequences of the global warming would be devastating. Therefore, global warming has to be mitigated at all costs and as soon as possible . Due to the insufficient reductions of carbon intensity on the supply side, the necessity to shift the focus on the consumption side has been highlighted. After a literature review about the distribution of emissions and associated socio-economic factors, the polluter pays principle is discussed. The methodological approach to our quantitative analysis is described, followed by the descriptive and multivariate regression analysis of household emissions.

Based on the results of our analysis, this last chapter will now discuss how reduction potentials can be identified for different household types and which policy instruments could be used to lower consumption-based emissions.

How to reduce emissions:

The total amount of CO2 emissions in a national economy (Em_{total}) can be calculated from the consumer perspective by the summing up all household emissions (Em_i = emission of each household $i \rightarrow n$) and adding the emissions caused by public consumption (Em_p)

$$Em_{total} = \sum Em_i + Em_p \quad .$$

The analysis focusses on household emissions as these constitute the bulk of emissions on a consumption basis. Households in Germany are responsible for around 69% of total emissions (Mayer and Flachmann, 2011:26;33).

By spending money on a particular good or service (M_{ij} = money household i spends on sector j) a household causes direct or indirect CO2 emissions depending on the sectors' carbon intensity (CI_j = carbon intensity of sectors $j \rightarrow m$) the money is spend on. The sum of each sector's carbon intensity and the money a household spends on it lead to the household's CO2 emissions.

$$Em_i = \sum M_{ij} * CI_j \quad .$$

Based on the analysis, we know that emissions are unevenly spread over the different households. As discussed in chapter 5 the carbon intensity differs largely between the sectors. 1000€ spent on transport causes almost 5-times higher emissions than 1000€ spent on services.

Given the distribution of a household's expenditures (x_{ij} = share of the household i spend on sector j ($\frac{M_{ij}}{M_i}$)), an average carbon intensity (ACI_i) for each household can be calculated. The average carbon intensity (ACI_i) is the sum of the product of each sector's carbon intensity (CI_j) and the share of the expenditure (x_{ij}) the household spends on this sector

$$ACI_i = \sum CI_j * x_{ij} \quad .$$

The product of the average household's carbon intensity and the household's money spent (M_i) therefore also gives us the total emissions of a household

$$Em_i = M_i * ACI_i \quad .$$

Given this relationship, there are two different ways to lower the Em_i : One is to lower the household's average carbon intensity (ACI_i) and the other is to lower the household's expenditures (M_i). To lower the ACI_i practically implies to shift the households consumption towards sectors with a lower carbon intensity. The value of ACI_i also decreases by reducing the carbon intensities of the different sectors through increased efficiency in these sectors. From the consumer's perspective, each sector's carbon intensity is an exogenous variable determined by the producers.

As long as the income level of each household remains a fixed variable, the conclusion would be that the reduction of every household's average carbon intensity is the main policy lever.

However, there are certain limitations to this approach: It implies a major exchangebility between the different consumption sectors which is not given in reality: Food for example can not completely be substituted by a lower carbon-intensive sector. A household will always need to purchase certain amounts of food. The same accounts for home energy, mobility, products and all other sectors.

Moreover, every expenditure in sector A also leads to certain emissions in other sectors. Going to a hairdresser (service) requires for instance a certain amount of transport energy. Therefore, the aim of reducing every household's average carbon intensity is limited and only possible for every Euro spent that exceeds the demand for basic needs. The reduction of ACI_i thus can be set as the major policy goal within the boarders given by basic needs and an impossible total substitution between the sectors.

Basic needs:

Before going on in with the implications, there is a strong constraint to this statement:

It is acknowledged that this debate is highly ethical and disputed. An acceptable definition has to be found of what basic needs are. One might certainly argue that a quick shopping flight from Berlin to London fulfils principle needs on the basis of freedom of choice. Without providing our very own definition and thereby avoiding a much needed public and scientific debate, we at this stage want to refer to research in the field of happiness. Moreover, basic needs cannot be solely defined on the basis of money and materialistic values. Insights from the field of happiness research and other areas in combination with a public debate could ultimately facilitate a democratic and widely acceptable definition of what basic needs are and what exceeds them.

As a thought-proving impulse we refer to the German social benefits debate. The German government argues that ALG II provides necessary amounts of money to fulfil each person's basic needs. However, regarding the continuous discussions about its fairness and the high number of lawsuits against certain aspects of ALG II, the definition has proven to be problematic.

Even though we believe that the question of what basic needs are has not sufficiently been discussed, we assume at this point that a certain minimum amount of money has to be available to fulfil the basic needs of a household. Therefore, the next section argues that especially low-income households have to be widely exempted from policy instruments aiming to reduce the ACI_i.

Discussion of policy implications

Different households emitt different amounts of CO2. Low-emitting households either 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 means the household is extremely poor) affect these households in order to maintain the fulfilment of basic needs.

The fact that emissions are rather concentrated towards high-emitting households suggests that a group of high-emitters would be affected the most by policy instruments implemented to reduce the ACI_i, followed by the large group of medium-emitters.

Fairness questions are raised. Should a small group of households have to radically change its way of consumption while some households remain exempted from changes? One might argue that some households have the right to emit more CO2 than others or that every household should further reduce its emissions.

Besides certain deviations between the household caused by differing basic needs, based on their socio-economic characteristics, e.g. spatial location, age, children etc., there is no reason why a certain household should have the right to emit more CO2 than another.

Here, the question of equity differs from income distribution debates, An unequal distribution of income might partly be legitimate due to different skills or just a different number of work-hours but a there is no similar social implication for carbon emissions – despite certain socio-economic factors and e.g. medical needs.

Yet, it describes an unrealistic case that every household emits the same amount of CO2. However, households which emit significantly more CO2 than others should bear the respective costs on the basis of the polluter pays principle (s.b.).

The analysis of this paper shows which socio-economic factors cause households to emit high amounts of CO2 and also provides information about the areas the emissions arise from. The analyses therefore gives us information about the impact of each socio-economic factor on the expenditure distribution x_i which is the endogenous variable for household emissions. We can therefore say:

x_i = f (income, education, …, employment status)

One way of changing the expenditure distribution (x_i) of a household to minimise its ACI_i would be to target the socio-economic factors of the household. However, only certain socio-economic factors are possible to alter. It does not appear useful or reasonable to strategically lower a household's educational level to mitigate emissions. This also applies to factors like age, gender and others.

Where socio-economic factors cannot be altered or it appears not useful to do so, the impact of the socio-economic factors can be targeted. As seen in results of our analysis, transport emissions of rural households is higher. Here, a shift away from fuel-intensive car usage towards more energy efficient public transport would change the household's x_i towards a lower ACI_i .

This example illustrates how our analysis allows to identify high-emitting socio-economic groups and to locate their major (emission causing) expenditures. Furthermore the data shows the amount of households that belong to these groups. With the given emissions of a socio-economic group and the quantity of households that belong to it, the socio-economic groups with the highest impact (big groups with high emissions) can be identified.

It goes beyond the scope of this paper to discuss the details of possible policy measures to reduce emissions on the basis of our analysis. However, the results provide useful information. The analysis provides an insight on who could be addressed by policy instruments in order to create a low-carbon society. Policy instruments based on the polluter pays principle could provide a guiding influence (e.g. a CO2 tax on very high incomes). Furthermore, specific incentives could be created. Policy could for instance reward smaller living spaces and larger household sizes (flat shares). Moreover, non-economical initiatives are possible: Students (upcoming high educated people with therefore high transport emissions) could be addressed by a campaign highlighting the different CO2 emissions / km travelling distance of a train and aeroplane.

As the household's emissions are given by $Em_i = M_i * ACI_i$, another way to lower a household's emissions (as mentioned above) would be a decline of the household's expenditures M_i . The implications following this more radical approach can not also be discussed here. Still, it remains an option to take this measure into consideration in case the success of changing the households' ACI_i does not lead to sufficient results. Then, further options would be needed to avoid the unprecedented and devastating consequences of climate change.

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