Distributional Impacts of Swiss Climate Policy

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Executive Summary

This report investigates how Swiss households contribute to concurrent greenhouse gas (GHG) emissions through their consumption and how the responsibility for these emissions is distributed across different parts of the population. By comparing these responsibilities across different population groups I observe trends that imply that costly emissions reduction will impact low-income households more than high-income ones. I discuss several options for policy making to counteract undesired distributional effects of climate policy.

Findings: High-income households emit the most per capita, low-income ones emit the most per CHF spent. The latter means that we have to expect that the direct relative impact of climate policy on low-income households' purchasing power is higher than for high-income ones. If climate policy were to focus on luxury goods alone, it could avoid this tendency but would not be able to come close to reaching a net-zero target. Private transport and residential heating cause large amounts of GHG emissions within Switzerland and are important to regulate from a Swiss climate policy perspective. I find that in private transport, high-income households are responsible for a larger share of the population's emissions than for residential heating.

Recommendations: Swiss climate policy has a clear focus on prescribing (e.g., by means of the MuKEn) and incentivizing (through the CO_2-levy and subsidies for energy-efficient renovations) emissions reduction in residential heating, but has little ambition for decarbonizing private transport beyond adopting EU emissions standards. Yet I find that, from a distributional perspective, it would make sense to emphasize emissions reduction in private transport where high-income households with their better ability to afford costly emissions reduction is responsible for a larger share of emissions than in residential heating. Thus, from a distributional perspective, expanding the Swiss CO_2-levy to include motor fuels in addition to heating fuels, e.g., may make sense. Switzerland should continue to recycle revenues from emissions pricing to households on a per-capita lump-sum fashion, since this is effective in keeping small the number of low-income, emissions-intensive

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households that are at risk to experience hardship. The literature on principle–agent problems suspects split incentives between landlords and tenants in the case of installing expensive but efficient heating technologies in rented dwellings. This risks that households without a choice in their heating system pay the CO_2-levy without being able to reduce emissions other than by not heating their home to their needs. Switzerland should make sure that renters and low-income credit-constrained households have access to low-carbon heating technology. Also the wide heterogeneity in emissions per household suggest that completely decarbonizing their consumption will be particularly expensive for some few households. Social security and non-governmental social safety nets have to be prepared for recognizing such hardship cases and for supporting them.

1. Introduction

The distribution of responsibility for climate change, through one's consumption, of different parts of the population has recently gained increased attention. Analyses of this distribution can be used to gauge how important it is that different parts of the population partake in the decarbonization effort. The World Inequality Lab of the Paris School of Economics, e.g., make the argument that the additional emissions caused by lifting everybody that earns less than US$ 5.5 per day above that threshold, could be compensated by the top 10 percent of global emitters cutting their emissions by one third (Chancel, Voituriez, & Bothe, 2023). At the same time, high GHG emissions also mean potentially high exposure to climate policy: those who emit large amounts of GHGs are also those who have to change their consumption patterns the most if we want to reach net-zero emissions.

This report sheds light on both these aspects of the distribution of GHG emissions across the Swiss population. It shows who is responsible for which share of emissions and through which parts of their consumption and it discusses what this means for policy design if one goal of such design is not to overburden certain parts of the population with policy costs.

Existing literature

Several reports and studies have been written to shed light on the global and national inequalities related to climate change. On a global level Oxfam America's Climate Equality report (Khalfan et al., 2023) and the World Inequality Lab's Climate Inequality Report (Chancel et al., 2023), provide insights as to how responsibility for global warming and wealth/income are correlated. They conclude that the bulk of the responsibility lies with the rich part of the world and that lifting the poorest out of poverty at the current GHG intensity of consumption can easily be compensated by meaningful GHG emissions reduction by the richest part of the population.

Chancel et al. (2023) present a similar analysis but also provide numbers for inequalities *within* countries. They find similar patterns within countries as across the global population: The richest are responsible for far more global warming than their share in the population alone would justify. For Switzerland, Sotomo's Energiewende-Index (Stückelberger, Bühler, & Hermann, 2024) provides additional detail. Based on a consumer survey and the numbers from two CO_2 calculators, the report provides estimates of global warming caused by different parts of the population and it differentiates different consumption categories such as *base level*, *housing*, *mobility* (subdivided into flying and driving), *consumption*, and *food*.[1] With respect to inequalities in responsibility for global warming, the study finds that GHG emissions correlate with income and age but to a lesser extent with place of residence. The focus of the study is on comparing actual emissions of households with their self-perception.

Contribution of this study

The aim of this report is to shed further light on how the responsibility for global warming is distributed across different parts of the population and across different consumption categories. It does so by employing survey data from the Swiss Household Budget Survey "Haushaltsbudgeterhebung" (HABE)[2] which covers almost 10'000 households and provides detailed consumption accounts. The data for household expenditures are combined with Life Cycle Assessment (LCA)s of the different consumption goods with respect to their climate impact to yield a well founded estimate for consumption based responsibility for global warming.

Beyond reporting different sub-populations' responsibility for climate change, this report discusses different conclusions that can be drawn from its results for policy making. High responsibility for global warming means high potential to reduce emissions and thus high exposure to the changes that climate policy tries to bring about. Depending on the nature of climate policy, its design should be wisely considered such that the impacts of policies are equitable across all or most groups within the general population. I find that including motor fuels (and transport emissions in general) in the CO_2-levy would make sense from the perspective of distributing direct policy impacts but I can also report that the revenue recycling mechanism of the CO_2-levy guarantees progressive[3] outcomes in either case.

In the following, Section 2 describes the methodology and results for my analysis of inequalities in responsibility in climate change. Section 3 discusses the possible implications of these findings for policy making. Section 4 summarizes my findings and concludes.

[1] In German: "Grundverbrauch", "Wohnen", "Mobilität: Fahren", "Mobilität: Fliegen", "Konsum", and "Ernährung".
[2] Bundesamt für Statistik, Haushaltsbudgeterhebung (HABE) 2015-2017
[3] A policy intervention is said to have a *progressive* impact if its net cost relative to income is higher for high-income households than it is for low-income ones. The impacts are said to be *regressive* if it's the low-income households that incur higher costs relative to income.

2. Responsibility for global warming

For the purpose of this study, a household's responsibility for global warming is determined by the GHG emissions related to the production and consumption of goods and services consumed by household members. This includes emissions from all GHGs and emissions caused across the globe. In order to make emissions of different GHGs comparable, they are expressed in terms of their Global Warming Potential (GWP) over 100 years compared to CO_2's GWP.

This responsibility is established by considering *current* annual consumption and thus accounts for *current* GHG emissions.[4] My measure of responsibility therefore counts the contribution of consumers towards current global GHG emissions, a number that needs to go to (net-)zero if we want to stop global warming at a level that is sustainable. It should not be confused with other measures of responsibility that try to establish different populations' (usually countries') share in cumulative past emissions and thus their share in responsibility in the current level of global warming caused since the beginning of industrialization. The latter responsibility for cumulative *past* GHG emissions is often used to argue that some countries have a higher moral duty than others to invest in fixing the problem of global warming or supporting countries with difficulties in decarbonizing their economy. The herein considered responsibility for *current* GHG emissions is more suited for identifying those parts of the population that need to change their behaviour most urgently. This can inform policy making in two ways. First, policies must ensure that emissions from all parts of the population and all important categories of consumption are reduced. An account of what parts of the population contribute to global warming through which categories of consumption can help assess if current or proposed policies do a good job at this. Second, policy frameworks should make sure that those who need to change their consumption patterns also have the means and incentives to do this. By identifying those who need to make big changes in consumption patterns and assessing if they have the capacity and face the right incentives to do so, we can derive suggestions for better policy making.

2.1. Methodology

In determining GWPs related with the consumption of different households, I follow and build upon previous work by Jakobs and Mutel (2023) which in turn implement methodology developed and described by Froemelt, Dürrenmatt, and Hellweg (2018). The different types of data and processing steps that are needed to arrive at numbers for per-capita GWP are shortly described in the following and discussed in some more detail in Appendix A to this report.

Data and data processing

I use survey data from the 2015–2017 HABE,[5] which gives information about income and spending for 9955 households (see Bundesamt für Statistik (BFS), 2022, for more information). HABE gives monthly spending in Swiss Francs (CHFs) for a fine grained classification of consumption

[4] That is the emissions from this year or some recent year in which the consumption goods in question were produced.

[5] Bundesamt für Statistik, Haushaltsbudgeterhebung (HABE) 2015–2017

goods. In addition to values in CHF the survey records quantities purchased for food and beverages (in kg or litres) and for motor fuels (in litres). For several categories of vehicles, white goods, and electronic equipment, the survey also establishes the number of items owned per household.

GWPs per consumption categories are given by Jakobs and Mutel (2023). For non-CO_2 GHGs, GWP has been determined according to the Intergovernmental Panel on Climate Change (IPCC)'s 2021 methodology for calculating the warming equivalent to a given amount of CO_2 over a period of 100 years. This makes the unit for GWPs "kg CO_2 equivalents (CO_2-eq)".

The GWP data by Jakobs and Mutel (2023) are expressly constructed for use with HABE data: The consumption categories of the two data sets match exactly and most GWP factors can be multiplied by units of consumption (CHF, kg, litres, or number of devices owned) available in HABE.[6] Where units do not match, the HABE data insufficiently relates to consumed physical quantities and additional calculations need to be made. Since energy goods like heating fuels are bound to make up a relevant part of households' GWPs, and since price differences across years and regions make spending in CHF an unreliable proxy for energy consumed, I convert CHF spent on fuels and electricity into energy consumed. For this, I take annual (and where possible regional) energy prices into account. For public transport, CHF spent on travel cards is a poor measure for distance travelled. To improve on HABE's information that is given as spending in CHF, I employ data from the Mobility and Transport Microcensus (Biedermann et al., 2017). The micro-census is a survey conducted by the Federal Statistical Office (FSO) asking Swiss residents about their mobility behaviour. I use km travelled on different modes of public transport for different household types from the micro-census and compare them with CHF spent according to HABE and derive a transport mode and household type specific conversion factor in km per CHF.

Categorizing households

To analyse which part of the Swiss population is responsible for how much GWP through their consumption, the set of households in the data from the HABE survey can be partitioned into different groups. HABE records a diverse set of socio-economic indicators that describe the entire household or its representative or household head (i.e., the household member that makes the largest contribution to total household income). Indicators describe properties such as "household size", "degree of urbanization", "ownership of residence" and many more. An important dimension along which GWP is discussed in the literature is income. In order to be able to control the size of the income groups I create my own partition into income quantiles. To this end, I need to define an appropriate measure of income and order households according to it. I observe that current (annual or monthly) income may fluctuate for some households due to special circumstances which households can compensate through intertemporal consumption smoothing. I thus view current consumption expenditures as a more reliable measure of how well off households are (of their lifetime income) than current income. Assuming that income is shared equally within a household, total income not only needs to be divided by the size of the household (giving per-capita income), but it also needs to be considered that the pur-

[6] GWP are estimates rather than precise numbers and Jakobs and Mutel provide mean, median, and standard deviation of the distribution of estimated GWP. For the purpose of this analysis, I use the mean estimates.

chased consumption goods (such as electronic devices, lighting, or room heat) are shared, and consumption is more efficient at generating consumer utility from a given amount of expenditure for big households than for small ones. The Organization for Economic Co-operation and Development (OECD) established a de facto standard for equivalence scales to compensate for this. This so-called "modified OECD equivalence scale"[7] measures the first adult in a household with weight 1 and additional adults with weight 0.5 and additional children with weight 0.3. Dividing total household income with this equivalence scale gives equivalent income.

Combining the above two considerations, I group households into income quantile groups[8] by ordering them according to their "equivalent lifetime income" which is proxied by dividing current household expenditures by the equivalence scale.

[7] See, e.g., https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Equivalised_income

[8] Quantile groups of (equivalent lifetime) income are constructed by ordering households according to income and grouping together those that are situated between quantiles of income. For 10-quantiles, or deciles, this means that the first decile group corresponds to the 10 percent of the population with the lowest (equivalent lifetime) income (their income is between 0 and the first decile of income). The second decile group comprises households with income between the first and second income decile, etc.

2.2. Findings

GWP per person

For establishing the responsibility for global warming on a per-person basis, the GWP from different consumption categories for a household are added up and divided by the number of persons in that household. By grouping households according to their socio-economic properties, averages for different household groups can be established and the typical GWP can be compared across the groups. At the same time, heterogeneity within such groups turns out to be large, and therefore, this report shows not only mean GWP per population group but summarizes the distribution of observations within those groups using box plots.[9] The boxes drawn in these plots are characterized by three (here horizontal) lines: the y-axis values for the observations at the first, the second, and the third quartile. The observation at the first quartile, e.g., is characterized by 25 percent of the observations having a lower y-axis value. The second quartile is thus the median observation: 50 percent of observations lie below it. The boxes are complemented by whiskers that reach out to the last observation that lies less than 1.5 times the interquartile range (the distance between the first and the third quartile) beyond the box. It is customary to plot outliers beyond the whiskers as explicit dots, but I abstain from showing them here, directing the attention to the main bulk of the ‘observations rather than to single observations. Superimposed on the box plots are the weighted means of the y-axis values within the respective household groups (depicted by an empty circle).

I find (equivalent) lifetime income to be the most important criterion for determining GWP. To see this, consider that lifetime income is strongly related to household expenditures. Figure 1 shows that, some considerable heterogeneity within income decile groups notwithstanding, per-capita expenditures increase notably for higher deciles of lifetime income. At the same time, emissions-intensity of consumption (measured as GWP per spending in kg CO_2-eq per CHF) is higher for low-income decile groups than for high-income ones (top panel in Figure 2), but this trend is weaker and the trend in per-capita spending dominates the overall trend in per-capita GWP shown in Figure 3 (top panel). At the same time, within–decile group variation in results is bigger for per-capita GWP than for per-capita spending, driven in part by the considerable within–decile group variation of GWP *intensity* shown in Figure 2.

[9] See Krzywinski and Altman (2014) for a more in-depth discussion of box plots.

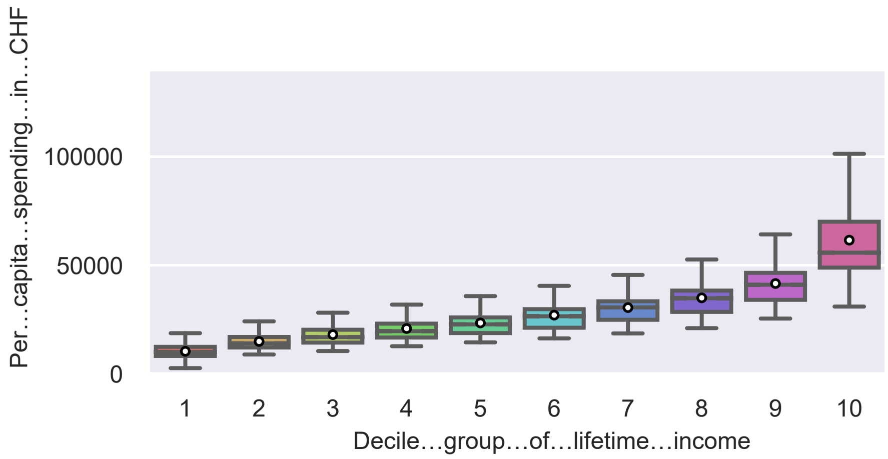

Figure 1: Annual per-capita expenditure within and across decile groups.

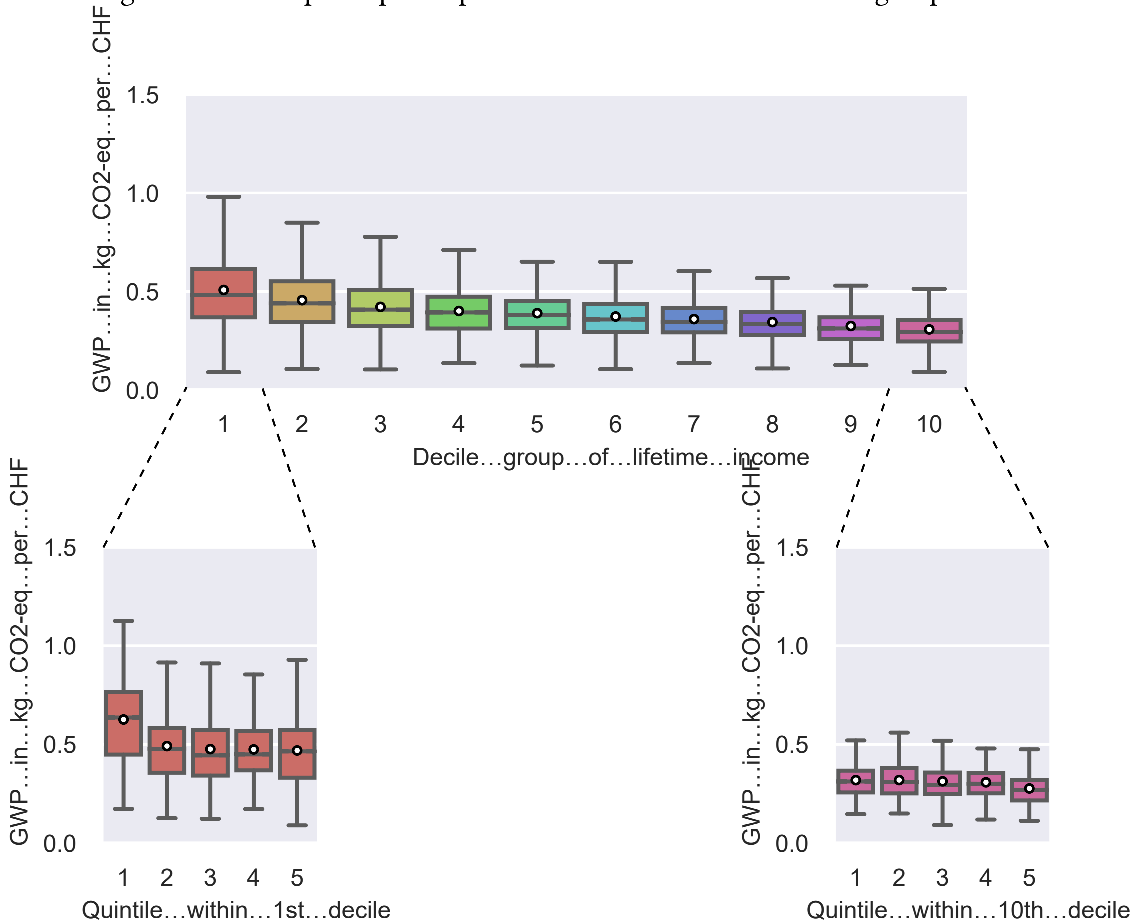

Figure 2: GWP intensity in kg CO_2-eq per CHF within and across decile groups (top panel) and within the first and tenth decile groups (bottom panels).

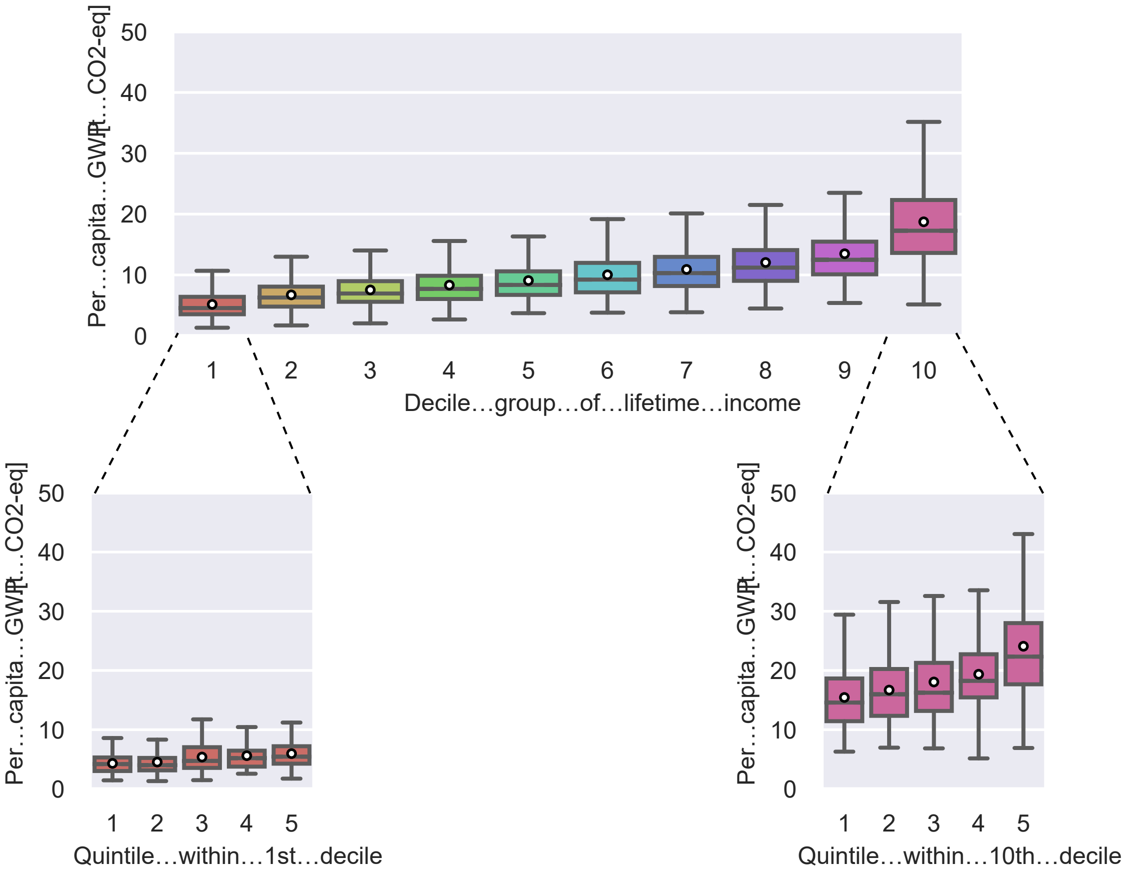

Figure 3: Per-capita GWP within and across decile groups (top panel) and within the first and tenth decile groups (bottom panels).

While we can identify clear trends of the means across decile groups of the population in the top panels of Figures 2 and 3, further subdividing decile groups into 2-percentile-groups (or quintile groups within decile groups; see bottom panels) does not add as much additional insight. In Figure 2 there is no clear and significant trend visible for GWP intensity within the tenth decile group. The figure for the first decile group suggests that the negative correlation between lifetime income and GWP intensity may also be at play within the decile group but the numbers of observations within decile sub-groups is not high enough to say this with confidence. (A more detailed discussion of this can be found in Appendix C). What we can say, is that the first 2-percentile-group has a higher mean GWP intensity than the following four. Similarly, in Figure 3, no clear trend is visible across 2-percentile groups within the first decile group, and a positive correlation between lifetime income and per-capita GWP suggests itself within the tenth decile group, with the highest-income 2-percentile-group showing significantly more per-capita GWP than the preceding four.

Among the other socio-economic descriptors along which the population can be divided, I find household composition, home owner status, and the degree of urbanization to be the ones that showed the most meaningful differences in per-capita GWP.[10] Figure 4 gives an overview of the results for these groupings of Swiss households. The top panel show that the household composition (in terms of number of household members and their age) is another relevant determinant of average per-capita GWP. If household heads are retired, the household's per-capita GWP is noticeably lower, and big households can use their economy of scale to live with lower per-capita GWP. The bottom panel shows that home owners, on average, emit more per capita than do residents who rent their home (left) and that residents of peri-urban areas (the "Agglomeration") have the the highest and the residents of urban areas the lowest per-capita GWP (even though this trend is not very distinctive).

The fact that the correlation of lifetime income and per-capita GWP is strong, and that households with different household composition, home owner status, and degree of urbanization will also have different income, begs the question if different GWP can just be explained by the income differences alone. The analysis in Appendix B shows that that differences in GWP across those three household properties persist if we differentiate them within decile groups of lifetime income. This suggests that these different household types have different per-capita GWP due to differing consumption patterns: They allocate their income in different ways across the consumption goods they purchase. This shall be further highlighted in the following.

[10]Besides household composition, home owner status, and the degree of urbanization, I checked gender of household head, canton of residence, region of residence, and pensioner status of household head.

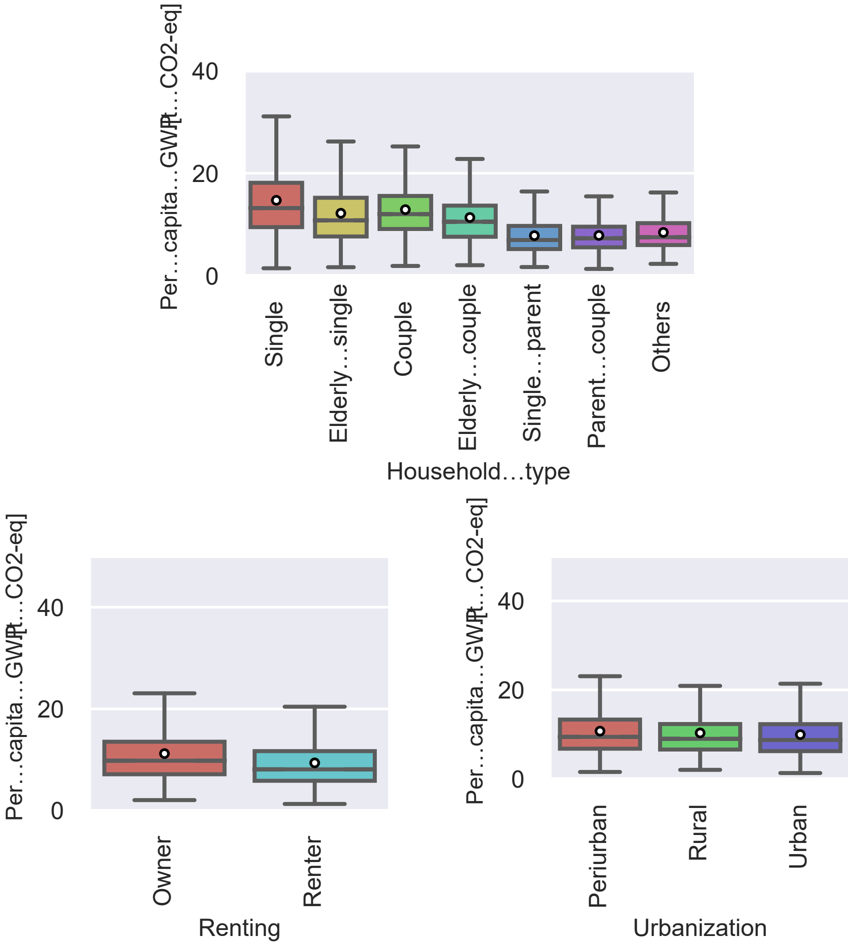

Figure 4: GWP within and across different sets of household groups. Top panel: Households grouped by household composition. Households are labelled "elderly" if one household member is aged 65 or older. Bottom panel: Households grouped by ownership of dwelling (left) and degree of urbanization (right).

GWP by category

Figure 5 shows how mean per-capita GWP is composed of contributions from different consumption categories. We see that the main contributors to GWP across decile groups are "food and drink", heating ("Central and district heating" plus "Gas and other heating fuels"), "private transport" (with the main component of gasoline and diesel consumption), and "electronic equipment". For households in decile groups of higher affluence, the emissions from these categories tend to increase. It can be noted that emissions from food, heating, and electronic equipment correlate less strongly with income than does private transport. For other categories of consumption, emissions make up a minuscule part in the first decile group but increase to relevant size for the more affluent decile groups. These consumption categories include goods that pertain to restauration and lodging, clothing and footwear, furniture and household equipment, hobbies, holidays, and education.

I note that a (costly) reduction of the emissions from the latter group of goods would not impact the lowest-income decile groups much but would on its own also not come close to reaching a net-zero emissions target. Without avoiding the emissions from "necessary" consumption goods like food and drink, heating, private transport, and electronic equipment, a net zero emissions world seems impossible.

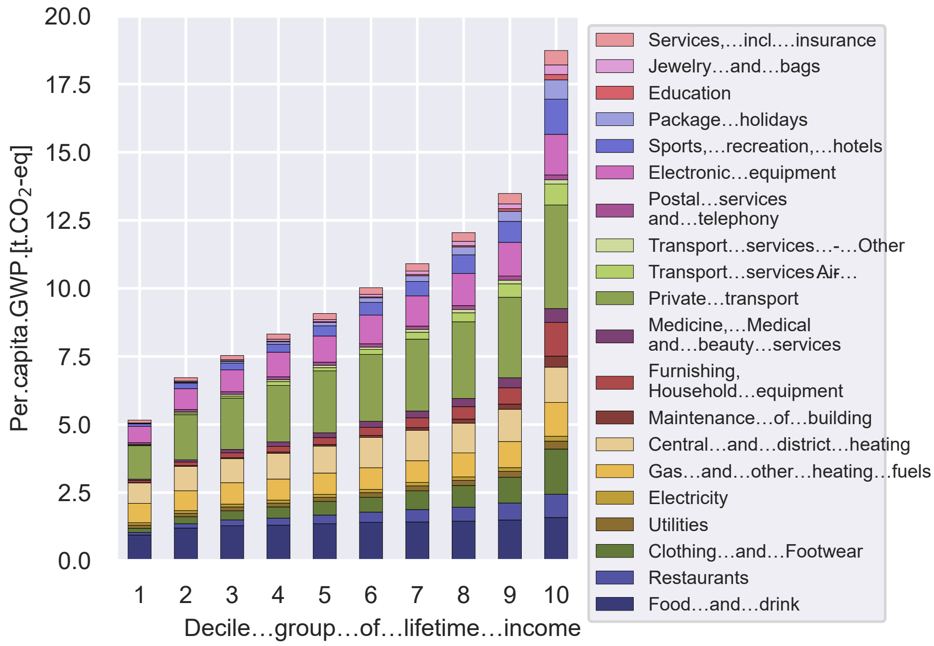

Figure 5: Annual per capita GWP from consumption across expenditure decile groups.

Figure 6 shows per-capita GWP from consumption related emissions for different household compositions in the top panel. Household composition is determined by the number of household members, their age, and their family status. The results show two main trends: First, households with elderly people are (on average) responsible for fewer emissions mainly because they use less transport, but their emissions from heating are somewhat higher. Second, the bigger the household, the lower are the per-capita emissions. They exhibit economies of scale for both transport and heating: Household members can share both cars and heated homes in order to enjoy a given level of energy services at lower per-capita expenses and emissions. An exemption is transport with the elderly. Elderly couples cause more per-capita emissions through transport than do elderly singles. The bottom panel of Figure 6 confirms that in per-household terms, big households do emit more for both transport and heating (compare "Single" with "Couple" households and "Elderly single" with "Elderly couple" households).

Figure 7 shows how per-capita GWP across categories depends on home ownership (top panel) and degree of urbanization (bottom panel). As seen in Figure 4 before, home owners, on average, emit more per capita than do people who rent their dwelling. While other consumption categories contribute to the difference as well, a big part of it is coming from emissions in heating. Home owners heat less with district and central heating and create more emissions through heating overall. Note that the HABE data does not allow for a conclusive answer about what causes these higher emissions because heating demand depends, among others, on the floor area that requires heating and on the quality of insulation, factors that are not captured by HABE.

The degree of urbanization is also predicting per-capita emissions in different households to a visible degree (lower panel of Figure 7). Here, it is transport that is the main driver of these differences. Households living in peri-urban settings have the highest per-capita emissions from transport, while households living in urban areas have the lowest. The same holds for overall per-capita GWP.

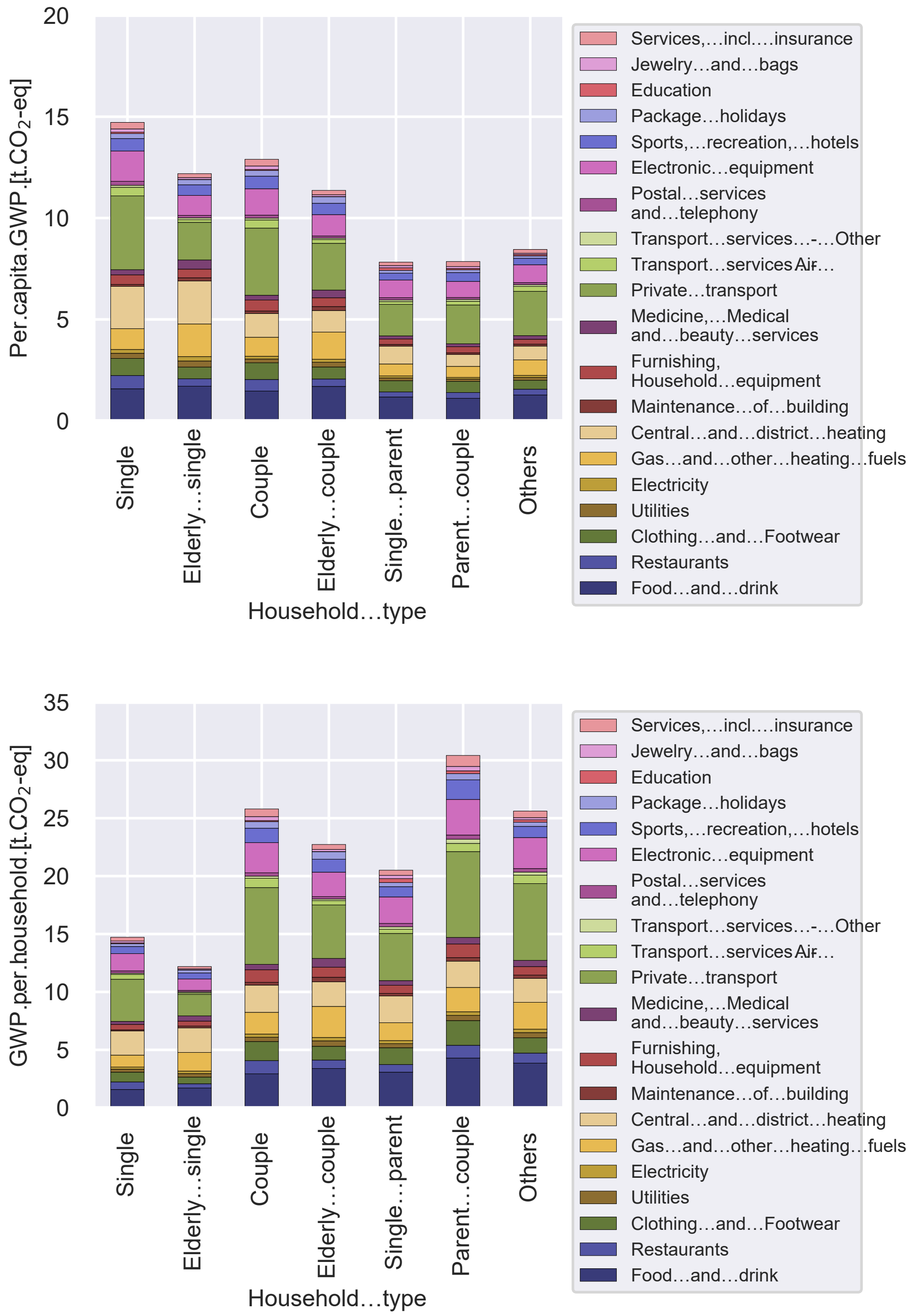

Figure 6: Annual GWP from consumption across different household types. Per-capita GWP is given in the top panel and per-household GWP in the lower panel. Elderly singles are aged 65 or older, elderly couples are couples where at least one person is aged 65 or older.

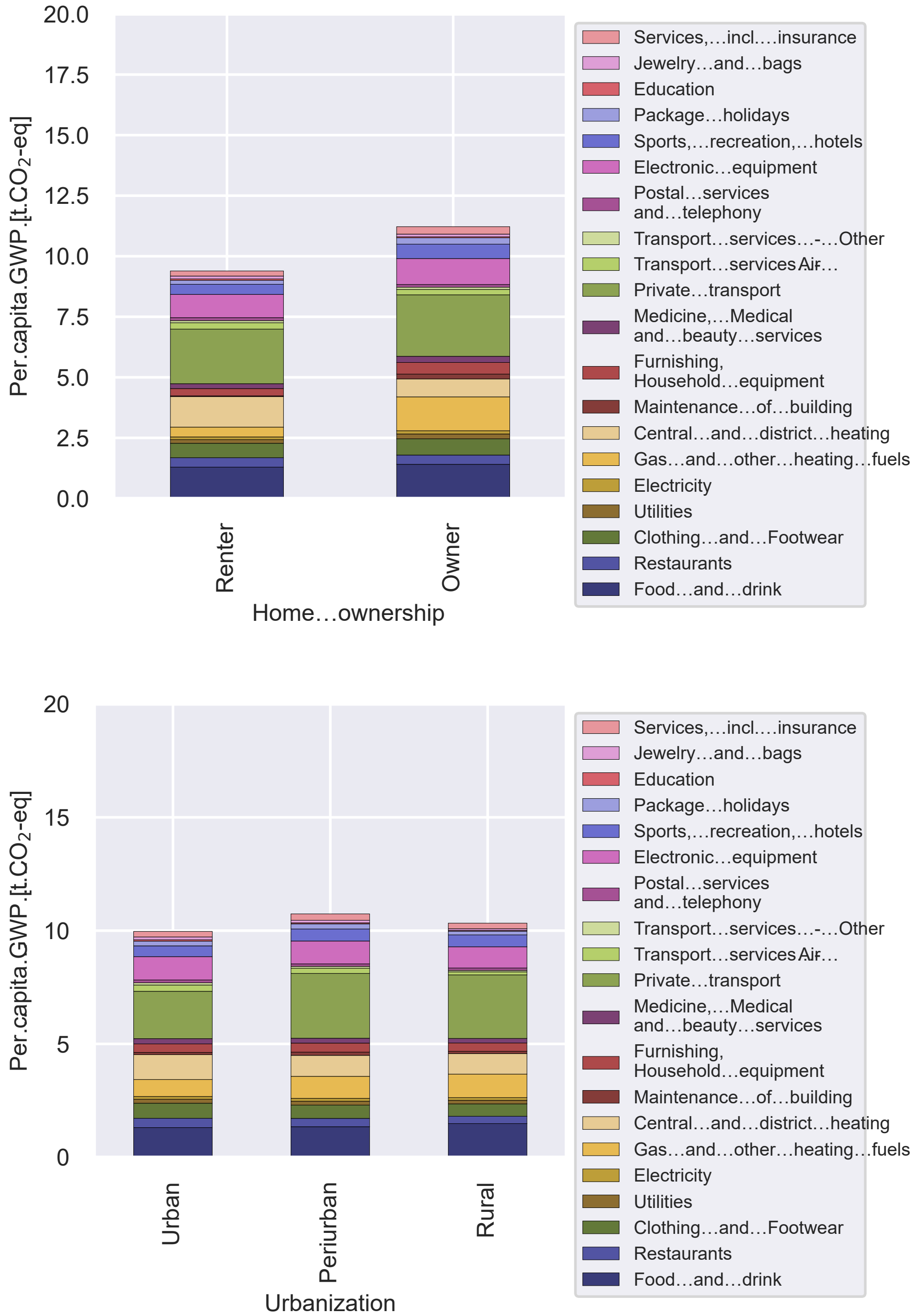

Figure 7: Annual per capita GWP from consumption across different household types. Households are differentiated by ownership of dwelling (top panel) or by degree of urbanization (bottom panel).

Transport and heating

Transport and heating are two of the most important categories of consumption in terms of GWP and their emissions arise mostly within the borders of Switzerland. They are thus central to Swiss climate policy targets and deserve closer examination. Figures 8 and 9 in their top panels show excerpts of Figure 5 for the two broad consumption categories transport and heating and subdivide the two into the most disaggregated categories that HABE provides. Two things become apparent.

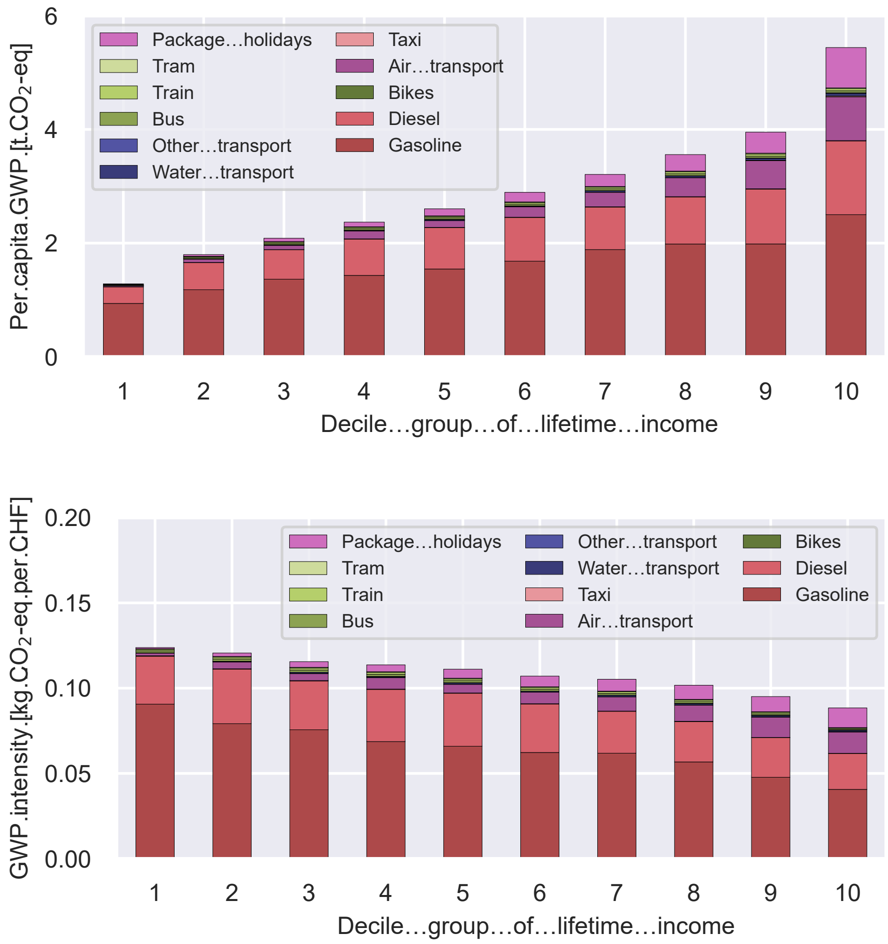

Figure 8: GWP related to transport across expenditure decile groups. The top panel shows annual per capita GWP, the bottom panel shows transport related GWP intensity of household expenditure.

First, different categories of transport contribute to overall GWP to different degrees. The fine-grained differentiation of transport modes and fuels (see Figure 8) reveals that GHG emissions from transport activities are dominated by fuel use for private transport. Other categories that matter are air transport and emissions from package holidays (but note that, besides transport, this category also includes emissions from heating hotels, etc.). The different modes of public transport account for a much smaller share of GHG emissions in Switzerland, since they are mostly driven by low-emissions electric power. The expenditure data from HABE does not allow for a very fine grained analysis of different heating fuels but much rather groups heating expenditures into direct payments for heating fuels (mostly by owners of dwellings) and payments for central and district heating (mostly by households who rent).

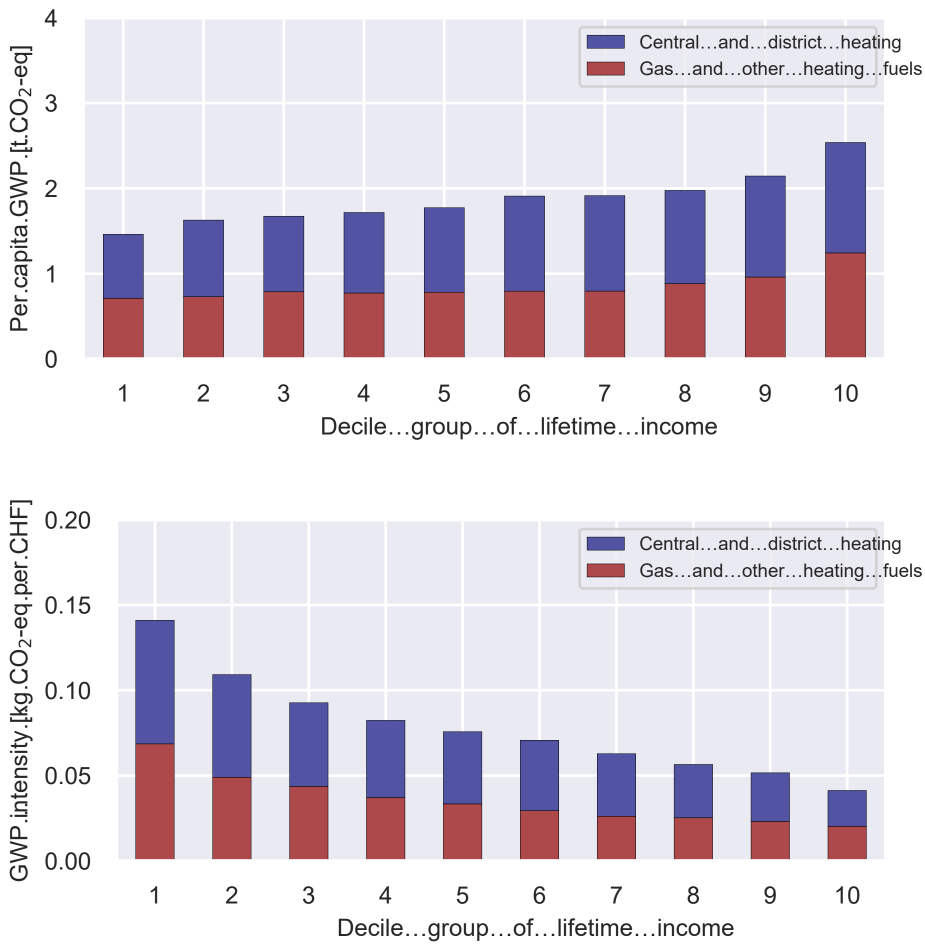

Figure 9: GWP related to heating across expenditure decile groups. The top panel shows annual per capita GWP, the bottom panel shows heating related GWP intensity of household expenditure.

Second, emissions (and thus exposure to policies requiring costly emissions reduction) rise much slower with income for heating than they do for transport. The bottom panels of Figures 8 and 9 emphasize this point by displaying GWP-intensity (emissions relative to overall household spending) for different decile groups. For both categories, low-income households emit more

GHGs per CHF (and are thus likely to incur higher costs from reducing emissions relative to their overall consumption budget) than do high-income households. But the trend is much stronger for heating than it is for transport and is even more extreme for air transport and package holidays.

Comparison with other studies

My findings by and large reflect those of other studies but also differ in some respects. Compared with Chancel et al. (2023), the share of responsibility for global warming of the richest part of the Swiss population is smaller. Several methodological differences may be the source of this. The academic literature has discussed the influence of using tax-records based data (the data base used by the World Inequality Lab) rather than survey data (used here) for assessing inequality. The comparisons tell us that the findings made by using the two types of data are mostly similar (see, e.g., Burkhauser, Feng, Jenkins, & Larrimore, 2012). Another, probably more important difference is that the World Inequality Lab does not only consider responsibility for GHG emissions through consumption but also through investing. Since particularly the rich invest some of their income as part of their savings decision, they have additional GHG emissions to answer for and this accounts for yet more responsibility for global warming with the wealthy.

Compared to Sotomo's study (Stückelberger et al., 2024) I use more detailed information about consumption patterns and their related GWP. While Stückelberger et al. identify transport and heating as the main driver of differences in consumption-related GWP within the population, their study treats the remaining consumption with a rather coarse resolution and miss some differences that occur particularly when comparing different income levels. When discussing the emissions of the richest they observe a noticeable increase in emissions from flying which I cannot reproduce with the HABE data. However, in their discussion of this group of the richest, they deviate from the literature's "convention" of comparing the richest 1 percent with the rest of the population and single out individuals with equivalent income greater than CHF 16'000 per month. In HABE there are less than 50 observations with an equivalent income of CHF 16'000 per month or higher and according to HABE's statistical weights, those observations represent roughly 0.5 percent of the Swiss population.

3. Climate policy design

The analysis above shows that different households have different responsibilities for consumption-based GHG emissions, and that emissions from some consumption categories such as passenger transport per air are mostly generated by the more affluent. Yet, the most important consumption categories for overall emissions are food, heating, transport and electronics, which make up significant shares in overall spending for low-income households in particular. This highlights the fact that we cannot get around increasing the cost of consumption for low-income households if Switzerland's net-zero emissions target is to be met (I assume that emission free technologies for producing different consumption goods are more expensive than their polluting counterparts at least in the short and medium run).

In the following, I explore some options for design of climate policy that allow protecting low-income households from disproportionate policy cost and make sure that high-income households do their fair share. The reasoning is that low-income spend their income mostly on necessities and are hurt more than high-income households by increasing costs of consumption and that low-income households may be credit-constrained and have difficulties to pay high up-front costs of investments for green (that is, non-GHG-emitting) technologies that may be even cost saving in the long-run. Another reason for "letting the rich go first" is that technology costs may decrease over time and that if those who can better afford it invest first, the cost of investments in green technologies may be lower when other, less affluent households make these investments later on.

3.1. Regulating for emissions reduction by high-income households

The analysis of emissions by consumption category and income decile group lets me identify several consumption goods the emissions of which could be regulated without affecting the consumption of low-income households too much. Examples for these appear to be air transport, lodging in hotels, and restaurant visits.[11] Policies that target such consumption goods specifically are almost certainly costing low-income households very little. But at the same time, emissions related to these consumption goods make up only a limited share of overall emissions that Swiss consumers are responsible for, and it is imperative that emissions from other, less conveniently distributed consumption goods be reduced.[12]

When regulating emissions from consumption categories that also make up a comparably

[11] In the case of restauration, where consumption is measured in CHF it is implausible that high-income households consume the same amount of calories per CHF as do low-income households. We have to expect that – contrary to my modelling assumptions – emissions per CHF spent in restaurants may be higher for low-income households than for high-income ones. My findings for how emissions from eating out in restaurants are distributed across income may therefore be biased towards overstating emissions for high-income and/or understating emissions for low-income households.

[12] It has to be noted that the effects of Swiss air travel on global warming are more significant than what the statistics presented in, e.g., Figure 5 suggest. On the one hand, HABE data only includes private travel, thus not directly accounting for business flights. On the other hand, the newest methodology for accounting for the warming potential of emissions in air travel suggests that CO_2 emissions in air travel have more serious consequences than elsewhere. All in all, air travel accounts for 27 percent of the global warming potential of Swiss domestic emissions (see, e.g., `https://www.parlament.ch/de/ratsbetrieb/suche-curia-vista/geschaeft?AffairId=20214259`)

big share in expenditures of low-income households (such as food, transport, heating, and electronics), policy makers can still try to design policies such that high-income households are incentivized to invest first, while green technologies are still expensive, and low-income households profit from lower cost established green technologies later. In markets where low-emission technologies are seen as a luxury good, this may to some extent be the natural market outcome. For battery electric vehicless (BEVs) it is argued that the market introduction worked smoothest, when Tesla initially catered to a niche market with a highly specialized sports car and only later reduced cost and provided more affordable cars to a wider audience. But policy may push this tendency even further by identifying *luxury* versions of given goods and regulating these more stringently than the non-luxury versions. This works best if the luxury version of a good is also more emissions-intensive. To remain with the example of cars, climate policy could aim to make non-CO_2-emitting technologies mandatory for large cars such as sports utility vehicles (SUVs) or two seated sports cars. Alternatively, fleet standards for CO_2 emissions per kilometre could be complemented by a maximum amount of CO_2 per kilometre *any* model within the fleet may emit (with potential exemptions for family cars with more than five seats).

But, admittedly, if we move away from transport the identification of luxury versions of goods becomes more difficult and regulating them may become more controversial. If we take the size of a dwelling (divided by the number of occupants, e.g.) as a measure of luxuriousness in the context of heating systems, and a retired couple lives in a spacious house they own, should they be forced to invest in renewable heating system even if they have difficulty affording the necessary investment from their savings? Or do we only demand a renewable energy heating system when the property changes hands?

To summarize, singling out luxury goods and focusing emissions reduction efforts on them may be possible in some cases but these make up a small share of overall emissions and if Switzerland wants to reach net-zero emissions, GHG emissions reduction efforts will also have to include transport and heating which will necessarily affect low-income households as well. The following section discusses to what extent low-income households may be impacted disproportionally by policy costs and makes some suggestions for policy designs to avoid this.

3.2. Protecting low-income households from disproportionate policy costs

Pricing CO_2 emissions in Switzerland

Climate policies at our disposal can generally be categorized in three types: carbon pricing, mandates for clean technologies, and subsidies for investments (or research) into clean technologies. Carbon pricing is viewed by many economists as a cost-efficient measure since all economic actors and markets see the carbon price and can use the information at their disposal for finding low-cost options to reduce emissions. Government mandates and subsidies on the other hand rely on the government to identify the best way for reducing emissions and run the risk of being much more expensive since the state does not have all the information about options for emissions reduction that the different actors in the different markets have. Landis, Rausch, Kosch, and Böhringer (2019), e.g., show that for policy design similar to the current Swiss policy framework, carbon pricing policies can be expected to keep overall costs of achieving emissions reduction significantly lower than policy packages that focus on mandating and subsidizing specific technologies alone. This efficiency argument and the fact that carbon pricing is an established policy instrument in climate policy (see, e.g., the emissions trading systems for energy-intensive industries in Switzerland and the EU, the CO_2-levy on heating fuels in Switzerland, and the recent expansion of emissions trading to transport and heating fuels [termed ETS 2] in the EU) makes it plausible that it will remain one of the corner stones of Swiss climate policy.

At the same time it is the policy that creates the highest direct policy cost to consumers even in the short term: Not only are consumers paying for more expensive green technologies if they reduce emissions, but they also pay the CO_2-levy on the emissions they have not yet avoided through such measures. And, again, the observation that the consumption of low-income households is on average associated with the highest emission intensity of consumption (their consumption causes more emissions on a per CHF-spent basis than higher-income ones, see Figure 2) suggests that the direct costs incurred from carbon pricing tends to impact low-income households most relative to their consumption budget.

This observation about direct policy cost has to be qualified by the expected effects of two additional mechanisms (indirect effects). One is driven by what happens in industries and markets when climate policy makes producers reduce emissions themselves. The consequence of costly emissions reduction in productive sectors is that real wages and capital rents decrease and this affects high-income households more than it does low-income ones. The second mechanism is part of carbon pricing itself and is subject to policy design choices: Carbon pricing generates revenues that can be employed in different ways and one way or another these revenues are recycled back to the economy, which can have its own distributional consequences.

For existing policies, the two mechanisms have been discussed in the academic literature at some length. For the indirect policy cost via reductions in wages and capital rents, the findings generally indicate that the regressivity[13] of the direct effects of carbon pricing on consumer prices is much reduced if not neutralized by the indirect effects. Rausch, Metcalf, and Reilly (2011) provide a transparent analysis and compare the direct (uses side) and indirect (sources side) effects on the distributional outcome of carbon pricing in the case of the US. But while the regressive effects on consumer prices are (mostly) neutralized *on average*, the wide heterogeneity in effects on low-income households[14] means that the most gravely impacted households are still among the low-income decile group (Landis, 2019; Landis et al., 2019). This highlights the necessity to further think about the distributional effects of how the revenue from carbon pricing is recycled. When I compare different ways of recycling carbon pricing revenue in a previous study (Landis, 2019), I find that lump-sum per-capita recycling (i.e., giving each Swiss resident the same amount of money; this is what is currently being done with two thirds of the revenue from the CO_2-levy) gives good results. This finding can by and large be explained by the fact that for low-income households, the lump-sum transfer is on average larger than their outlays on the CO_2-levy, while the direct costs of the CO_2-levy exceed the lump-sum transfer in the case of high-income households. Figure 10 shows the resulting

[13]A policy or an aspect of policy design is called regressive, if its cost to low-income households compared to their expenditure budget is higher than the cost to high-income households *on average*.

[14]The wide heterogeneity of emission intensity in Figure 2 shows main the source of this heterogeneity of outcomes.

impacts of carbon price based Swiss climate policy on consumer utility in 2035 and 2050 and their distribution across households in income quintile groups. It becomes evident that relative consumption utility impacts on low-income households, *on average*, are smaller than those on high-income households. Yet, the households with the worst utility impacts are still to be found in the lower-income quintile groups, even with revenue recycling in place.

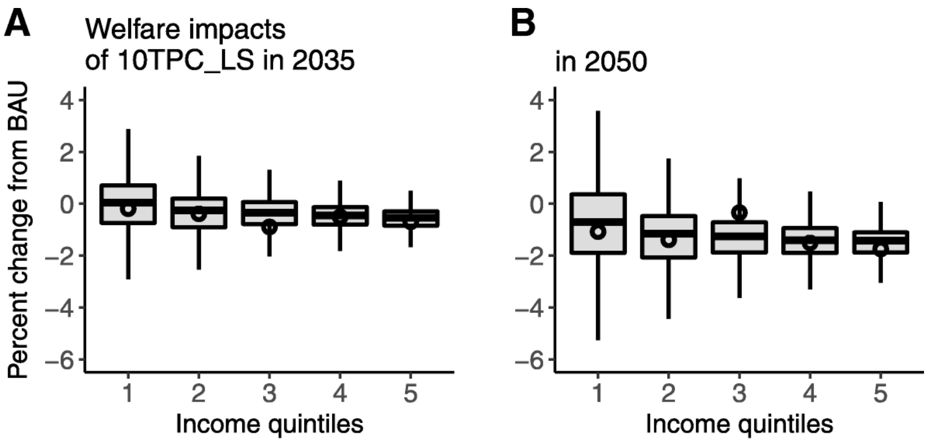

Figure 10: Welfare costs of carbon price based climate policy for Switzerland in 2035 (panel A, left) and 2050 (panel B, right) according to Landis (2019). Two thirds of carbon pricing revenue is recycled back to households in a per-capita lump-sum fashion. "Welfare impacts" of climate policy reflect how much more or less consumption utility households are able to achieve relative to the consumption budget in the baseline (equivalent variation relative to baseline expenditure budget).
Source: Landis (2019)

Pricing GHG emissions globally

The findings above are for pricing of CO_2 emissions in Switzerland. But as time goes by, the scope of climate policy should expand (to other GHGs as well as to other regions). In the following, the findings in Section 2 shall be used for illustrating that similar patterns can be expected to apply if climate policy encompasses all GHGs from all around the globe. From the point of view of Swiss consumers, this may occur, e.g., if all GHG emissions in Switzerland are regulated using the same or similar emissions prices and imports are taxed at the borders for their embodied emissions.[15]

[15]European climate policy is currently moving into that direction. Recently, the EU has decided to regulate emissions of motor and heating fuels with a second emissions trading system, thus moving closer to price based regulation of all domestic GHG emissions. And the border carbon adjustment mechanism (CBAM) that is currently being put into place acts as a pricing of embodied GHG emissions at the border. For Switzerland, National Council member Gerhard Pfister proposed a policy package similar to what I consider here (`https://www.parlament.ch/de/ratsbetrieb/suche-curia-vista/geschaeft?AffairId=20220451`). It was not met with enthusiasm by the Council of States, but may resurface when the discussion turns to climate policy beyond the year 2030 (`https://www.tagesanzeiger.ch/klimaabgabe-abgelehnt-gerhard-pfisters`

I restrict my analysis to the short term. That means after introduction of emissions pricing, firms do not adjust production processes, and all they can do is increase prices according to the emissions associated with their production. Equally, households do not adjust consumption patterns but just face higher costs with constant expenditure budgets.[16] Without such adjustments, the additional costs of consumption goods from emissions pricing is the product of the consumption goods' emissions content and the emissions price. For exploring the qualitative distribution of impacts of a price on global GHG for Swiss consumption, I assume that emissions are priced at CHF 100 per tCO_2-eq.

The upper panel of Figure 11 shows the mean direct cost of such an emissions price on households in the ten decile groups (blue solid line). As low-income households have smaller expenditure budgets the amount of emissions related to their consumption is small as is their direct cost from emissions pricing compared to high-income households. I assume that the revenue from this is collected by the government and fully redistributed to households in a per-capita lump-sum fashion. The resulting additional refunds for households are shown in Figure 11 as the dashed red line. (The fact that this line is not perfectly horizontal is due to the fact that it show the averages of *per-household* revenues and that average household size varies slightly across decile groups.) It becomes apparent that low-income households pay less for carbon pricing than they are refunded and vice-versa for high-income households. This shows that – in analogy to national CO_2 pricing – global GHG pricing can be turned into an overall progressive policy if emissions pricing revenue is redistributed in an appropriate way.

While the upper panel shows averages only and absolute numbers in CHF, the lower panel of Figure 11 shows the distribution of net impacts (refunds minus direct costs) across households within decile groups and measures them relative to the baseline expenditure budget. This rendering shows that, in terms of averages (depicted by circles in the figure), the net benefits relative to household spending are larger for low-income households than the net costs for high-income households. It also shows that, due to large heterogeneity within income decile groups, the households with the highest relative net cost are still situated in the lowest income decile group.

The findings can be summarized similarly for pricing of global GHG emissions as they do for national CO_2 emissions. The visible direct cost of emissions pricing to households look regressive (this assessment is for the short term; in the medium to long term, indirect effects on markets for labour and capital services may neutralize the regressivity). Recycling of the revenues from emissions pricing can counteract the (perception of) regressivity in direct costs if properly designed. Per-capita lump-sum recycling makes overall policy distinctly progressive, but heterogeneity in low-income deciles means that hardship cases among the group of lowest-income households may still occur.

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[16] As previously mentioned, this neglects medium to long term adjustments in both production and markets for labour and capital services. Similarly to the analysis of national CO_2 pricing, an analysis that allows for medium to long term adjustments to global GHG pricing would probably yield results that are skewed to slightly higher progressivity compared to what I find here, but similar heterogeneity within income groups (compare to findings by Landis, 2019; Rausch et al., 2011).

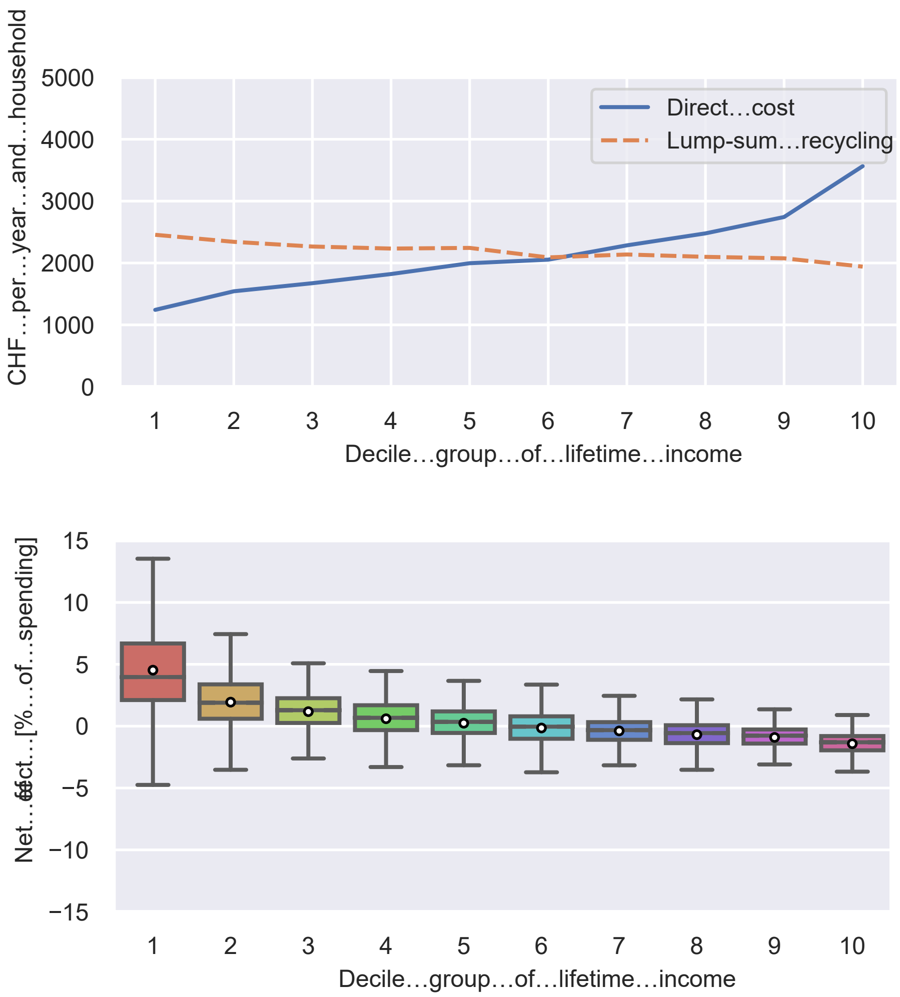

Figure 11: Short term effects of global GHG pricing for Swiss consumers. Top: Direct cost of GHG pricing (blue solid) and per-capita lump-sum recycling (dashed orange). The lines represent averages across households within decile groups.
Bottom: Net cost (direct cost minus lump-sum recycling) relative to baseline household expenditures. Box plots describe the distributions of net cost within the ten decile groups, the circles denote mean net cost within the groups.

Additional considerations

So far the analysis was based on the relation between policy cost and the baseline expenditure budget. Another issue often raised with less wealthy households and individuals is that they are restricted in their possibilities to invest due to credit constraints. In a somewhat similar vein, households who rent their dwelling have little influence over the heating technology and insulation standards employed in it. These two issues may hamper the ability of renters and lower-income house owners with little wealth (e.g. house owners with big mortgages) to efficiently react to the current CO_2 levy on heating fuels.

If we do not want to risk the CO_2-levy being restricted in its effectivity to (wealthy) house owners, we should make sure that everybody can react efficiently to the incentives set by the CO_2-levy. For credit constrained house owners, marketing schemes like 'Mietkauf' may be a valid solution.[17] Under such schemes, house owners pay for the energy services over time and providers pay for the upfront investment for installations of efficient technologies. Information about them should be promoted and a healthy competition between providers should be ensured. For renters, the situation is less straight forward. Market rents for housing should, in principle, account for the fact that efficient but more costly heating systems reduce heating costs and should be worth more rent. But not everybody is convinced that landlords are sufficiently aware of these trade-offs and that they make the efficient investments if they are not directly confronted with emissions pricing. The empirical evidence on this question seems mixed. Recent research suggest that if tenants are made aware of the energy cost savings, their willingness to pay for this through increased rents is commensurate (Lang & Lanz, 2021) and that market outcomes show little differences between flats that are offered for sale and those offered for rent in Germany (Singhal, Sommer, Kaestner, & Pahle, 2023). Yet, in other contexts, financial incentives seem to have stronger effects for owner-occupied dwellings than for renter-occupied (Charlier, 2015). One suggestion for addressing this potential problem is to either complement financial incentive with building standards and renovation requirements or to replace the incentives with such policies entirely (Charlier, 2015).

In view of the fact that we cannot be certain that all actors in the economy can react efficiently to a CO_2-levy that focuses on heating fuels it may be regarded as suboptimal design that the CO_2-levy excludes motor fuels where such split-incentives problems do not exist. In addition to that, the distributional properties of pricing emissions from motor fuels are more favourable for low-income households than pricing emissions from heating fuels. To see this, compare bottom panels of Figures 9 and 8. A more in-depth critique of the exemption of transport from emissions pricing in Switzerland can be found in Landis, Rausch, and Kosch (2018).

4. Summary and concluding remarks

The analysis of how consumption based responsibility for GHG emissions, or GWP, is distributed across households allows for the following observations:

- Where luxury goods are emissions-intensive, climate policy that focuses on these goods can ensure that high-income households do relatively more in terms of emissions reduc-

[17] See, e.g., `https://www.energieheld.ch/renovation/finanzierung/mietkauf`

tion than low-income ones. But if we restricted ourselves to regulating luxury goods, the scope for significantly reducing emissions towards a net-zero target would be very limited.

- When emissions across the board are reduced, and if policy induced emissions reduction is costly, this will cost low-income households more (relative to expenditure budget) than high-income ones (regressive direct effects).
- Emissions pricing provides revenue for counteracting regressive direct effects. The current design of the CO_2-levy recycles two thirds of the revenue to households in a per-capita lump-sum fashion. This makes the CO_2-levy overall progressive.
- High heterogeneity in consumption patterns may result in hardship cases (but their number can be significantly reduced by good policy design). Swiss society should be prepared to recognize hardship cases and support them.
- The distributional properties of policies leading to costly emissions reduction are more favourable for emissions reduction in private transport compared to heating. But the current CO_2-levy only prices heating fuels and exempts motor fuels. The observation that there are split incentives between investors and users of clean technologies in the case of heating but not for private transport would make transport even more attractive for carbon pricing.

While the method used here for deriving GWPs from expenditure data and LCA is state-of-the-art, a few limitations have to be noted. Since the LCA that I used here does not differentiate consumption goods' quality levels by households of different income, there are possible differences in emissions per unit of consumption that may not be captured. In the case of public transport, I try to take this into consideration by denominating the LCA with person kilometres (pkm) and finding income dependent numbers of how far people ride per CHF spent on travel cards. For goods categories like restauration and clothing, the same was not done. Yet it is plausible that high-income household consume less per CHF spent in terms of physical units for both eating out and clothing than do low-income households. This may bias my analysis towards attributing too many emissions to high-income households and too few to low-income ones. Another drawback of my data sources is that the survey data contained in HABE are a few years old. No newer survey data are made available by the FSO, since the COVID-19 epidemic created irregularities in consumption patterns, and these are deemed to make the data unreliable. As a third caveat, it has to be noted that some observations about household expenditure patterns do not seem to represent "normal" monthly household expenditures. The HABE makes an effort to account for the fact that not all consumption goods are consumed every month of the year and asks households to give their *average* monthly expenditures based on annual bills for such consumption goods. Still some observed household patterns look "irregular". This may be due to strong deviations from normal monthly values for consumption goods that are not reported as monthly averages based on annual bills or to the yearly values deviating from normal values. This means that some of the most extreme values in Figures 1–4 and 11 may represent atypical situations of the concerned househols.

Finally, the observations made about the usefulness of revenue from emissions pricing for controlling the overall distributional impact of climate policy has to be qualified by the observation that such revenue may be abundant in the short term, when emissions are still high, but may dwindle even with rising emissions prices as emissions themselves go to zero in the longer term.

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Appendix A. Additional detail for the data processing routine

The combination of the LCA and household survey data in the HABE as described in Section 2.1 can mostly rely on harmonized units in the two data sets. That is, if GWP in the LCA is given in kg CO_2-eq per CHF spent or per kg or litre consumed, HABE provides consumption measured in the respective units. But some exceptions exist. These include heating, electricity, and public transport, where HABE gives expenditure in CHF but the LCA insists on physical units like Megajoule (MJ) or pkm travelled by mode of transport.[18] The following gives more detail on how these consumption categories are treated in my data processing routine.

Mobility: In the case of public transport modes (bus, tram, train), HABE gives households' expenditure for travel cards. Due to the fact that travel cards can allow for unlimited use of transport on certain lines or in certain areas over a given amount of time, it depends on the intensity of use of such travel cards how much pkm of transport services corresponds to the purchase price. This matters to the extent that different types of households may display different behaviours in terms of how intensively the travel cards are being used. Thus, the strategy is to find additional information about how far different household groups travel per CHF spent on different modes of transport. Within the groups, pkm travelled is taken to be proportional to spending.

The summary statistics of the Mobility and Transport Microcensus (Biedermann et al., 2017) provide information to this effect. Table "Tagesdistanz" in the "Verkehrsverhalten der Bevölkerung, Synthesetabellen"[19] contains daily distances for respondents in different household types. HABE can be used to obtain the expenditure on tickets and travel cards for different household types. The resulting ratios of pkm and expenditures then gives appropriate conversion ratios from CHF into pkm for different household types.

But which household types to differentiate? Table "Tagesdistanz" allows for taking subgroups of the Swiss population according to geographical region, language region, degree of urbanization, household composition, sex, age, household income, and status of employment. For combining with expenditure data from HABE, I consider the dimensions geographical regions, language, household composition, and income. For deciding which dimension of household typification to focus on, I take averages of spending (in HABE) and the numbers for pkm (from the micro-census) and look at the correlation of the two along the dimensions. The dimension that gives the lowest correlation gives the most additional information complementary to estimating pkm as proportional to spending. I find the correlation to be the lowest along the dimension household composition and I conclude that household composition is the household property that provides the most additional information. I therefore consider household composition–specific ratios of pkm travelled per CHF spent as the conversion factors of expenditure to travel distance. Expenditure on multi-mode travel card expenditure is divided into distance travelled on different transport modes taking household composition–specific

[18] My routine for combining LCA and expenditure data is driven to a large extent by the units used to denominate GWP in the LCA given by Jakobs and Mutel. Other consumption categories such as restauration and fashion probably have varying GHG emissions per CHF spent for different household types. Yet, since the LCA gives GWP in kg CO_2-eq per CHF, I use this constant value across all differently household types.

[19] Retrieved as file `su-d-11.04.03-MZ-2015-T01.xls` from `https://www.bfs.admin.ch/asset/de/2503927` on 27 February 2024.

mode shares into account.

Heating and electricity: For housing related utility expenditures, households differ in their reporting detail. Some households can report all expenditures explicitly, others report expenditure for general utility expenditures that may include fees for waste disposal, waste water, fresh water, heating fuels, heat (from district or central heating), electricity, and "other". My strategy is to split this general utility expenditure into the different subcategories according to the (average) expenditure shares of those households that report explicitly. For establishing the shares, I differentiate households that own their dwelling and those who rent.

For spending on waste disposal and energy, I make the following additional considerations. Waste is only taken out of general utility bills for those households that have no explicit expenditure for waste already. In the case of energy, I take heating and electricity out of the general utility bills if explicit energy expenditures is half the size of spending on general utility bills, taking this low ratio as an indicator, that explicit energy spending does not cover everything.

For heating, even after splitting up general utility costs, approximately one third of households does not have any expenditures for heating. I fill in missing numbers in proportion to households' overall housing expenditures (rent or mortgage payments plus utilities) such that their average agrees to the averages of households that do report heating expenditures.

After these adjustments to spending records, I need to convert expenditures into physical quantities where the LCA units require it for assessment of embodied GHG emissions. This is the case for energy carriers like heating fuels, electricity and heat from district and central heating (in MJ), but also for waste (number of waste bags; cubic metres of waste water) and water (in cubic metres). For waste, waste water, and water, I use the price estimates used by Froemelt et al. (2018) that were kindly provided by Jakobs and Mutel. These price estimates are differentiated by region (eight cantons plus rest of Switzerland) and household size.

For energy, I take different reasons for differing prices into account. On the one hand, energy prices may vary over time, on the other hand, non-linear price plans make the average electricity price dependent on the volume consumed. For electricity, I use ElCom electricity tariffs per canton, year, and user profile (annual energy consumption).[20] For heating, rather than using time dependent price data, I use aggregate Swiss heating demand for the years 2015–2017 in MJ and distribute that across households were surveyed in the respective years in proportion to their expenditures for heat.

[20] Available at, e.g., `https://www.visualize.admin.ch`

Appendix B. Income and other household types

I find that lifetime income (viz. expenditures) is an important determinant of how much GWP different household types are responsible for. When I differentiate Swiss households along other socio-economic dimensions, I can create further groups of households with differing GWPs but this may be confounded by the fact that these new groups themselves have different lifetime income on average. In the following I try to make sure that the GWP patterns across different household types are not merely due to the different household types having different lifetime incomes, but that they reflect genuinely different consumption behaviour of the household types.

Figures 12–14 show the separation of households into the two statuses of house ownership, into different household compositions, and into different degrees of urbanization – but this time within each decile group. Since the differentiation within decile groups yields the similar trends as does the differentiation within the whole population of surveyed households, I conclude that the differences in GWP across household types are not mainly driven by correlation between household types and lifetime income, but there is one exception to this.

Households living in a peri-urban setting, in the total of surveyed households, are responsible for the highest level of GWP (Figure 4). But within single decile groups (so somewhat controlled for income), we see that it's actually the households living in rural areas that have the highest level of GWP caused by their consumption (Figure 14).

The remaining trends observed across all surveyed households (Figure 4) remain true when controlling for income: Households living in urban areas are responsible for the least amount of GWP (Figure 14), households who rent are responsible for smaller amounts of GWP than those who own their residence (Figure 12), and larger households, on a per-capita basis, cause less GWP with their consumption than do smaller ones (Figure 13). This rather clear trend, observed when controlling for income, is attenuated a somewhat in Figure 4, however, indicating that bigger households tend to be of higher lifetime income which additionally increases their GWP when not comparing for income.

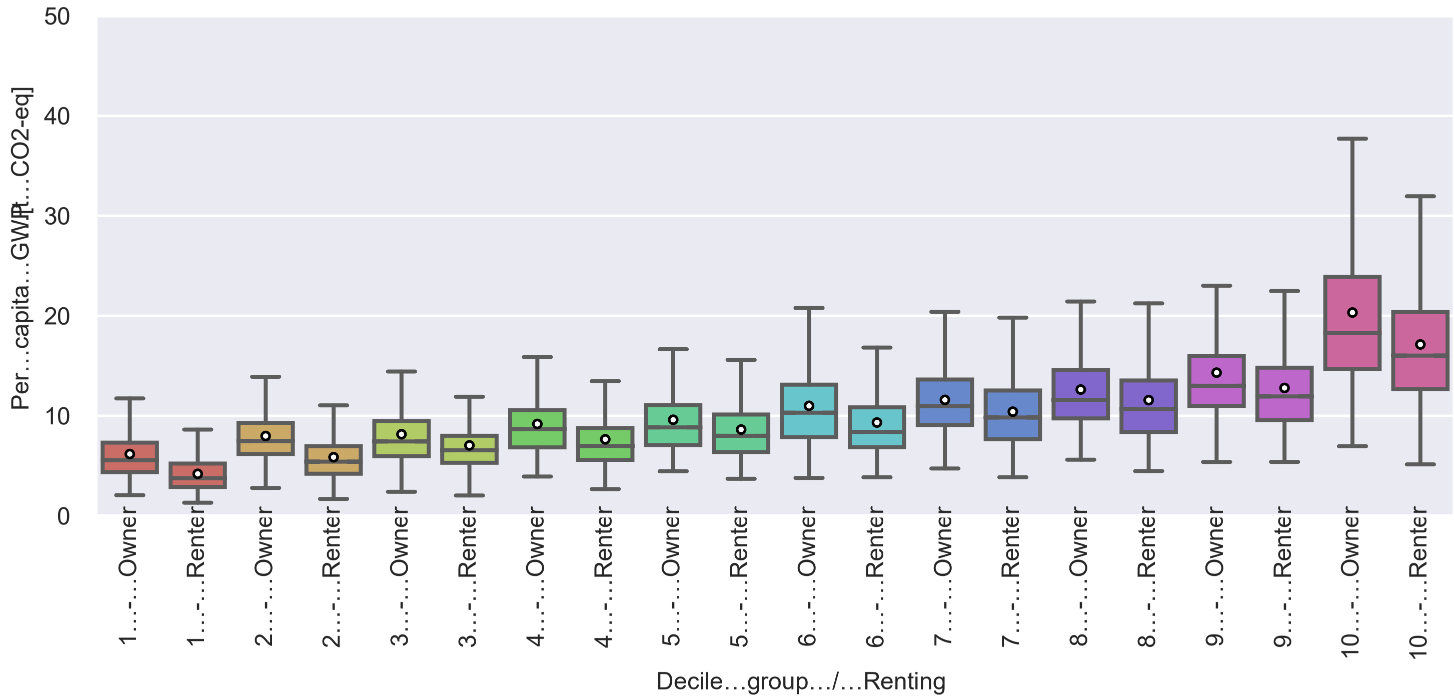

Figure 12: GWP grouped by house ownership and by decile group of lifetime income.

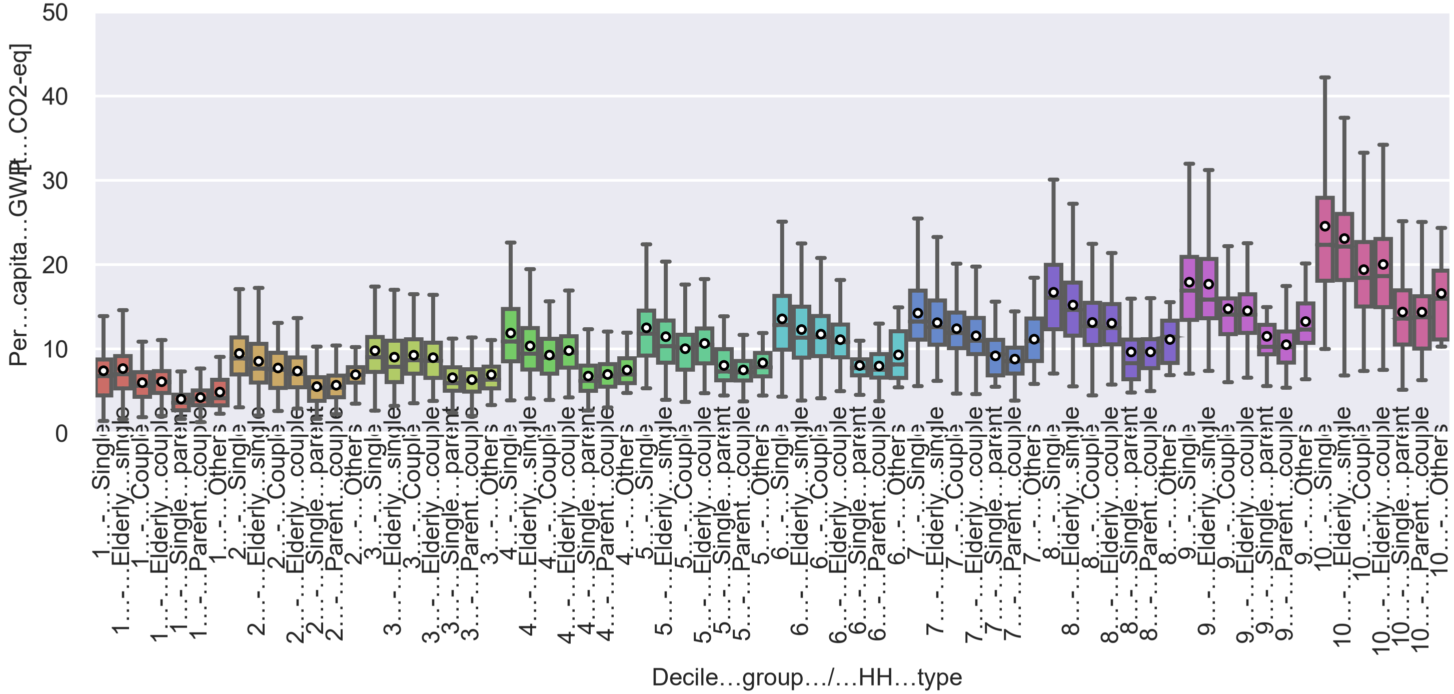

Figure 13: GWP grouped by household composition and by decile group of lifetime income.

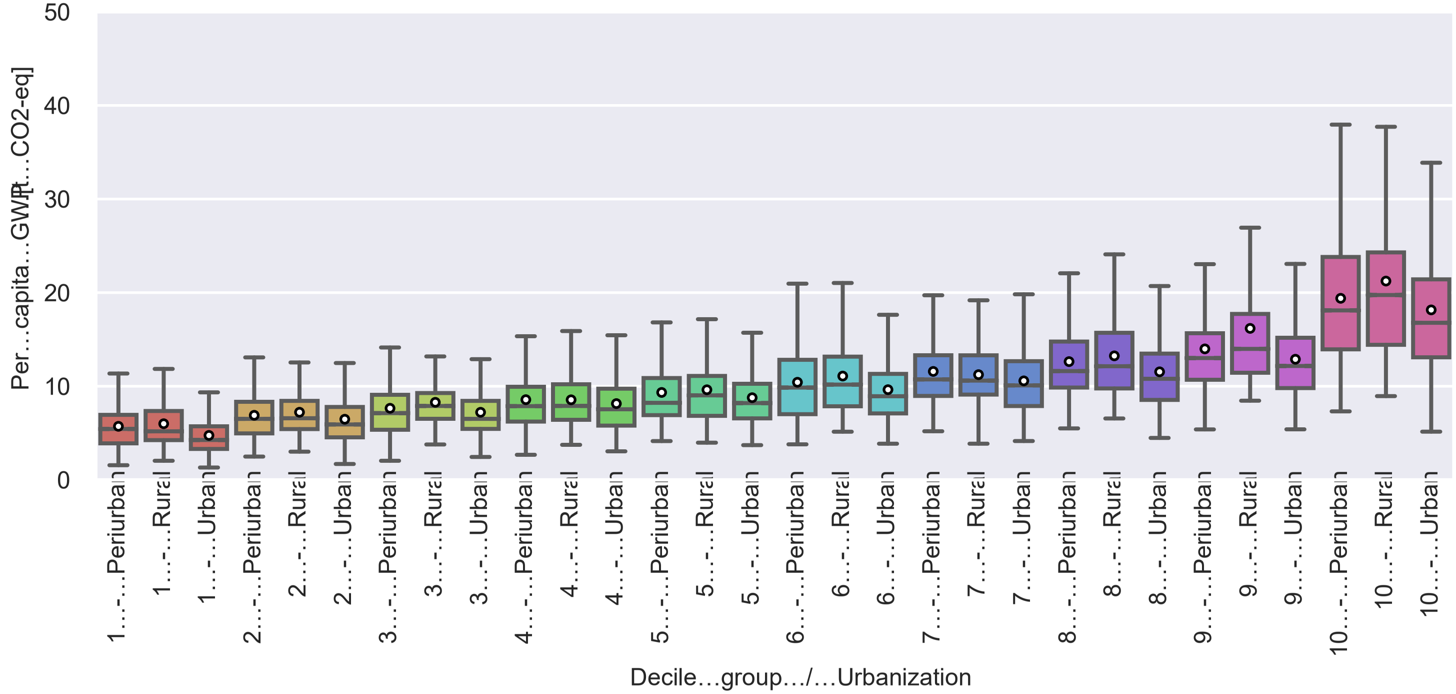

Figure 14: GWP grouped by degree of urbanization and by decile group of lifetime income.

Appendix C. Confidence in found trends – comparing trends across decile groups and across 2-percentile-groups

Several trends for the means of per-capita GWP and GWP intensity have been observed in Section 2.2. The confidence with which I can say that these trends are real and not just due to a peculiar set of observations depends on the confidence intervals that I attach to these means and thus on the number of observations that are available for a given part of the population in HABE. With around 10'000 observations in the whole sample, I have around 1000 observations per decile group, whereas for 2-percentile-groups the number is approximately 200. I therefore have to expect tighter confidence intervals around decile group means and wider ones around 2-percentile-group means, giving us higher confidence in trends that we observe across decile groups than in trends across 2-percentile-groups.[21]

This intuition about the size of confidence intervals is by and large met by the results in Figures 15 and 16, which show the confidence intervals for the means in Figures 2 and 3, respectively. Figure 15 shows the situation for GWP intensity in kg CO_2-eq per CHF. Here, the trend across decile groups is clear in the sense that we observe a strictly monotone decrease in lifetime income. The confidence in the trend is not perfect but still distinct: The confidence intervals for means in neighbouring decile groups overlap, but at least confidence intervals between one decile group and its second-nearest neighbours are disjoint. For 2-percentile groups, no monotone trend can be affirmed, most confidence intervals overlap with several others, but we can say with confidence, that the mean GWP intensities of the two lowest income 2-percentile-group are higher than the those of the other 2-percentile-groups.

The trend for per-capita GWP across decile groups in the top panel of Figure 16 is also clear: Mean per-capita GWP increases with income and we are highly confident in our observation since the confidence intervals of the ten means never overlap. For the 2-percentile-group numbers in the bottom-panel the situation is less clear. Even though we can suspect a monotone trend, the confidence intervals of numerous pairs of means overlap and I cannot be confident of the trend. What I can say with some confidence, however, is that the last 2-percentile-group (the one with the highest lifetime income) has the highest per-capita GWP.

[21] Confidence intervals around the mean m are determined as $m \pm 1.96 \cdot s/\sqrt{n-1}$, where s is the (weighted) sample standard deviation and n the number of observations in said sample.

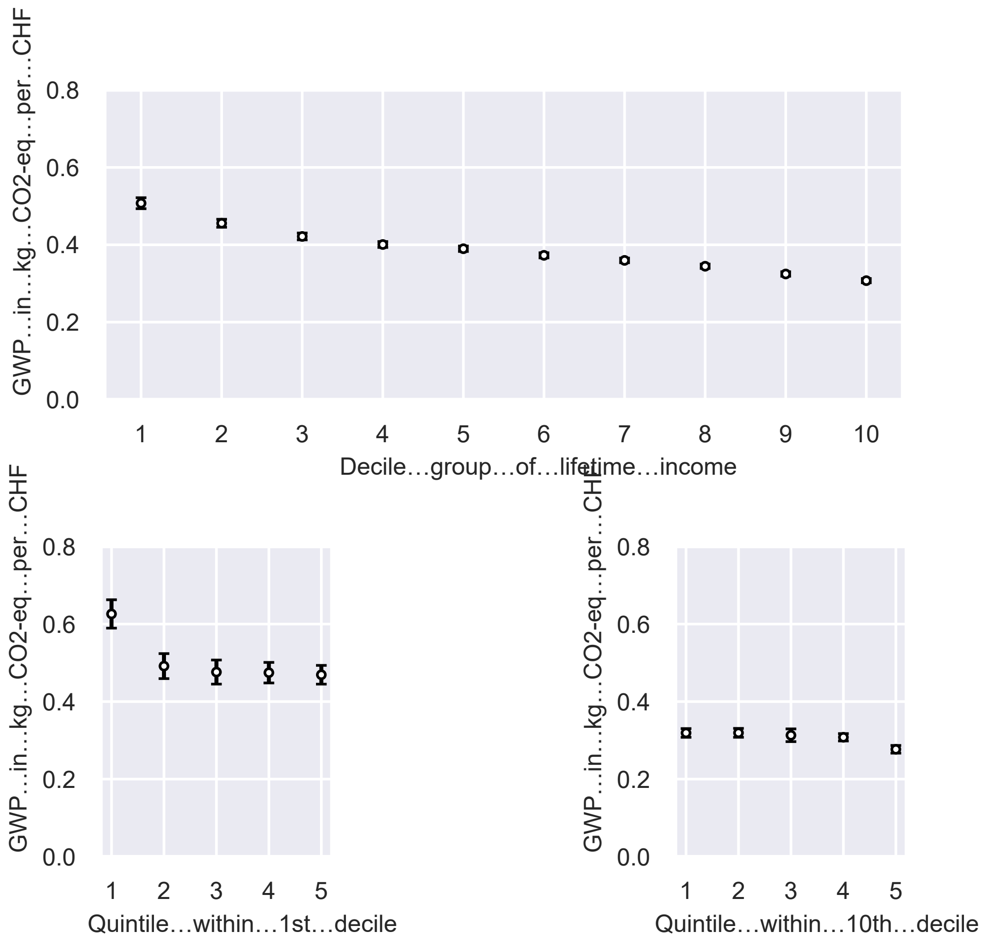

Figure 15: 95 percent confidence intervals for decile group means of GWP intensity of consumption (top panel) and for 2-percentile-group means (bottom panels).

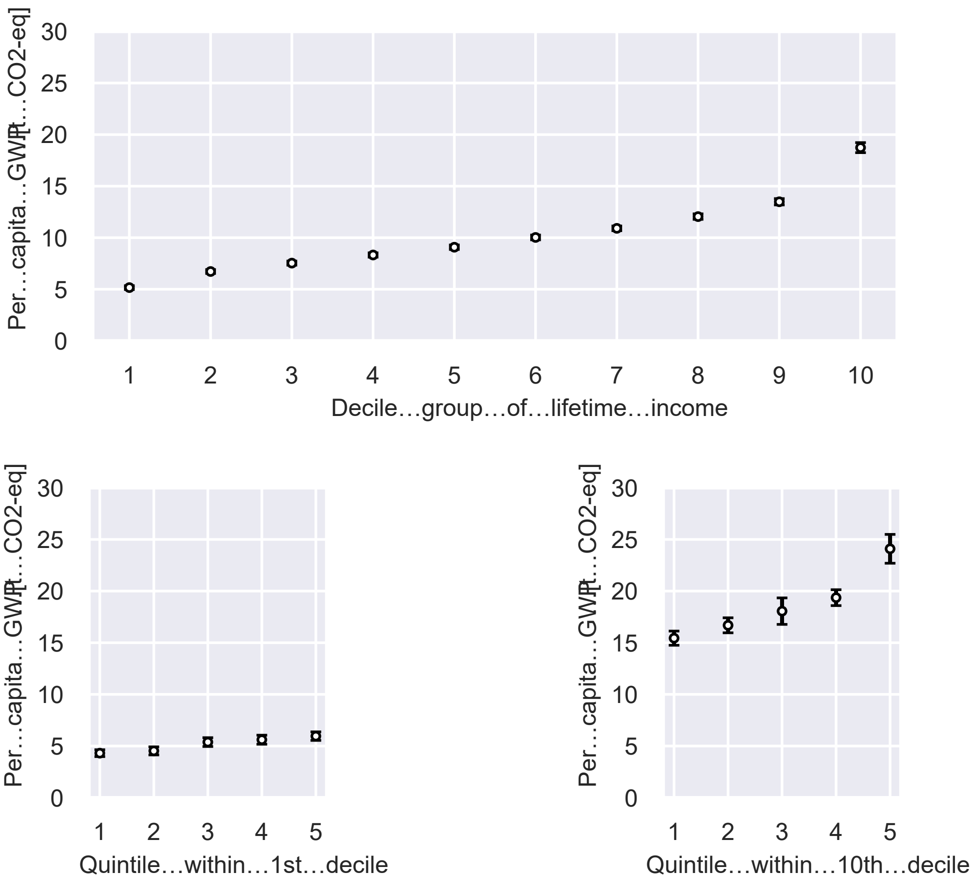

Figure 16: 95 percent confidence intervals for decile group means of per-capita GWP (top panel) and for 2-percentile-group means (bottom panels).