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The Material Footprint of Private Households in Germany: Linking the Natural Resource Use and Socioeconomic Characteristics of Users from an Online Footprint Calculator in Germany

Abstract

Footprint calculators are efficient tools to monitor the environmental impact of private consumption. We present the results of an analysis of data entered into an online Material Footprint calculator undertaken to identify the socioeconomic drivers of the Material Footprint in different areas of consumption, from housing to holidaymaking.
We developed regression models to reveal 1) the impact of socioeconomic characteristics on Material Footprints of private households and 2) correlations between the components of Material Footprints for different arrays of consumption. Our results show that an increasing Material Footprint in one array of consumption comes with an increasing Material Footprint in all other arrays, with the exception of housing and holidaymaking. The socioeconomic characteristics of users have a significant impact on their Material Footprints. However, this impact varies by the array of consumption. Households only exhibit generally bigger Material Footprints as a result of higher incomes and larger dwellings. We conclude that indicators which strive to monitor resource efficiency should survey disaggregated data in order to classify the resource use to different population groups and arrays of consumption.

Keywords: sustainable consumption; resource use; online survey; feedback

1. Introduction

The growing demand for natural resources, and raw materials in particular, increasingly affects the world's ecosystem and places a burden on efforts to counter environmental pollution and climate change (IRP 2017). In the majority of industrialised countries, the total amount of materials used in the economy (including materials from imports) per capita and year is an average of 40 to 50 tonnes (Bringezu et al. 2009). At the same time, Lettenmeier et al. (2014) and Lettenmeier (2018) have suggested that a global sustainable level of Material Footprint per capita per year, for private consumption alone, is eight tonnes only. As a consequence, sustainable resource management requires appropriate consumer policy at both international and national levels (with different reduction goals depending on the current resource consumption in a country).

Germany published its first sustainability strategy in 2002 and since then has reported various indicators for measuring the development of sustainability in that country, including resource efficiency, striving to double raw material productivity (raw material input in the economy in relation to the GDP) by 2020 relative to 1994. The latest update, in 2016, adopted the framework of the Sustainable Development Goals (SDGs) (German Federal Government 2016), which were introduced by the United Nations in 2015 (UN 2015). The German Resource Efficiency Programme (ProgRess II) is directed towards achieving the target formulated in the German sustainability strategy as well as to contributing to fulfilling the SDGs on resource efficiency (BMU 2016). For instance, Sustainable Development Goal 12 encourages more sustainable consumption and production patterns through measures that minimise the use of natural resources.

In 2017, the UN General Assembly adopted a corresponding indicator framework for the SDGs, which was developed by the Inter-Agency and Expert Group on SDG Indicators. The indicator framework states that Sustainable Development Goal indicators should be disaggregated, where relevant, by income, sex, age, race, ethnicity, migratory status, disability and geographic location, or other characteristics. However, the indicator for SDG 12.2 that measures efforts to achieve the sustainable management and efficient use of natural resources by 2030 only covers the Material Footprint per capita without differentiating any further (UN 2017).

Germany's National Programme for Sustainable Consumption also aims to implement the Agenda for Sustainable Development, and therefore specifically identifies relevant consumer policies. The programme has concluded that behavioural changes in favour of more resource-efficient consumption is still hampered by obstacles such as a lack of information, and differentiated, personalised feedback. The programme suggests providing such information by introducing the use of carbon and resource calculators (BMU 2017). Such footprint calculators are an element of Green Information Systems (Green IS), which emerged in online and mobile applications over the last decade to assist users in adopting green behaviour by providing personalised information (see Mallet et al. 2013 or West et al. 2016, Collins et al. 2018, Mulrow et al. 2019). Watson et al. (2008) refer to Green IS as the design and implementation of information systems that contribute to sustainable business processes. According to them, Green IS, for example, helps to provide information to consumers so they can make green choices more conveniently and effectively (Watson et al. 2008, p. 3). In this sense, individual footprinting allows one to identify the environmental "hot spots" and can help to identify appropriate measures to reduce the personal footprint (Fitzpatrick et al. 2015).

The Wuppertal Institute provides such an online resource calculator that enables consumers to examine their consumption patterns by calculating their own Material Footprint. This online tool provides personalised information on users' Material Footprints and makes suggestions for behaviour changes in favour of more sustainable behaviour. Moreover, the footprint calculator gathers socioeconomic information on its users, enabling researchers to disaggregate and classify users' Material Footprints according to sex, age and/or income.

Against the background of the SDG indicator framework (which suggests classifying users by socioeconomic characteristics), and Germany's national programme (which suggests providing personalised feedback thus prompting behavioural change), the aim of this paper is to carry out those proposals with respect to resource efficiency by presenting an analysis of one online Material Footprint calculator. We aim to show whether the Material Footprint differs between population groups according to their socioeconomic characteristics and along different arrays of consumption from housing to holidaymaking. This way, we are able to analyse not only the influence of socioeconomic characteristics on the Material Footprint in different categories of consumption, but also analyse how the Material Footprints in different categories of consumption relate to each other. For instance, whether a decrease in resource use in one consumption category comes with a decrease in other categories and vice versa. Thus, policies on sustainable consumption in specific areas such as housing or mobility can be better informed about their effectiveness. Policies striving to decrease the resource use in one array may spill over to other areas or may be cancelled out by an increase in other areas, *e.g.* due to rebound effects (Buhl 2014, Buhl and Acosta 2017a). Accordingly, our research addresses the following questions:

1) Which socioeconomic characteristics influence the Material Footprint of consumers?

2) How do the Material Footprints in different consumption categories relate to each other?

We start by introducing the data of the footprint calculator and the underlying Material Footprint calculations. Section 2.2 describes the method applied to answer the research questions. Section 3.1 presents descriptive results and bivariate relations between the socioeconomic characteristics and the Material Footprint of users. Section 3.2 presents our results from a multivariate, inferential statistical analysis. Section 4 discusses the sampling and methods, summarises the findings and draws conclusions on how to disaggregate Material Footprint data.

2. Data and methods

Natural resource categories are equivalent to abiotic and biotic raw materials from used extraction (put to economic use) and unused extraction (e.g. overburden from mining).

In national accounting systems that monitor material flows within and between national economies (see Bringezu (2009), the term Total Material Requirement (TMR) is widely used for this type of resource accounting[1].

More recently, the Material Footprint has been introduced into international material flow accounting as a consumption-based indicator that includes imports (Wiedman et al. 2015). It accounts for the domestic extraction of raw materials (raw material equivalents) from the final demand by households, businesses and governments, but not the unused extracted material. As well, Schoer et al. (2013) compare the RME of consumption for the EU-27 based on different Input-Output (IO) tables not covering unused extraction as well. Giljum et al. (2015) exclude exports and refer to Raw Material Consumption (RMC) as the Material Footprint (MF) by applying a global, multiregional input-output model (MRIOT). Steinberger et al. (2010) report the global domestic material consumption (DMC) which corresponds to RMC in economy-wide material flow accounts (EW-MFA). In contrast to our study, all of the above analyse international resource use relying on economy wide material flow accounting and IO approaches. Lutter et al. (2016) give an overview of the predominant approaches to calculate Material Footprints based on IO data.

Other recent studies combine material intensities (or CO2 intensities) from aggregated IO tables and survey expenditure data in order to give a more differentiated picture of the

[1] The TMR is part of a set of Material-Flow-Accounting indicators that differentiate between direct and indirect inputs (I), consumption (C), extraction (E), unused (U), domestic (D) and total (T) material flow categories. For example, the indicator of domestic material consumption (DMC) is often used to account for raw materials used in a economy.

Material Footprint of private consumption (Gill and Moeller 2018, Pothen et al. 2018, Buhl et al. 2017a). Buhl et al. 2017a for example used an extended MRIO model to generate material intensities of the main areas of expenditures (first digit in the COICOP classification) and matched these intensities with the expenditures of households in the German federal state of North-Rhine Westphalia in order to describe regional resource use over time.

Lopéz et al. (2016) give the material footprint in terms of Construction Material, Biomass, Fossil Fuels and Metals and multiply them by income levels provided in the Household Budget Survey from the Spanish Statistical Office. They show that the Material Footprints increase as income level in Spain increases (scale effect). Junnila et al. (2018) as well as Ottelin et al. (2018) calculate the Material Footprint of consumption terms of the Total Material Consumption (TMC) by multiplying expenditure and material intensities derived from environmentally extended Input-Output data. This way the authors are able to differentiate the Material Footprint along income classes as well as ownership of dwelling, heating system and cars (Junnila et al. 2018) and household types in terms of age and family status (Ottelin et al. 2018).

However, Material Footprints using input-output data either need to be reconciled (affecting robustness and aggregation of results) with expenditure data based on COICOP (Classification of Individual Consumption According to Purpose) categories or compute (iterate) the demand for commodities. Moreover, those approaches imply a proportional relationship between expenditure and footprints. Rising expenditure may not necessarily result in higher resource use though. Consumers may as well shift consumption to high-quality goods with less material intensity.

2.1 Data

The Material Footprint of the study at hand is calculated on the basis of the lifecycle material input of all goods and services used by a household or rather persons living in households. While all calculations are related to one individual (person per year), some areas of consumption can only be calculated by also considering other household members (*e.g.* the Footprint of electricity use is drawn from the overall electricity use of the household and divided by the number of household members).

The material resource use includes natural material resources required for raw material extraction (including those for recycling), the production and use of processed materials, products and services for private consumption, and any other activities undertaken to meet household needs. Private consumption is the personal consumption by consumers for food, housing, energy, clothing, health, leisure, education, communication, transport as well as hotels and restaurant services. The calculation procedures of the Material Footprint used in our disaggregating analysis, are based on total lifecycle material flow accounting of products and services, covering also unused extraction and calculating the Material Footprint directly from the information given by consumers in a single survey . For example, information on the type of house a consumer lives in as well as his living space is needed in order to account for the construction and dismantling of a similar building in Germany that has a lifetime of at least 50 years (for a more extensive description of the method, see Schmidt-Bleek 2009, Liedtke et al. 2014, Wiesen et al. 2014, Greiff et al. 2017, Wiesen & Wirges 2017 or Teubler et al. 2018).

Since only a limited amount of questions can be integrated with this approach and consumers are often unable to give specific information (e.g. on their excact electricity use), assumptions are used to fill the gaps. These assumption are mostly based on country averages (*e.g.* the average fuel consumption of a private car in Germany) or represent a typical consumption pattern (*e.g.* the typical opening hours and number of users in a fitness centre). However, the survey design uses specific and physical consumer inputs whenever possible and especially for those areas of consumption that have the highest impact on the environment (*e.g.* car routes in km or number of portions of meat per week; see the supplementary material for the full questionnaire).

Calculations based on life cycle assessment (LCA) of survey data rather than on national material flow accounting in input-output modelling enable researchers to draw a more direct, disaggregated picture of the Material Footprint of private households without the underlying uncertainties of combining input-output data and survey data. The weakness of the approach is its lack of comprehensiveness (often underestimating the overall effect), as parts of the upstreams material and energy flows are cut-off to be computable while also many smaller consumption choices cannot be integrated into a survey design (see Lutter et al. 2016).

In this respect, the Sustainable Development Goals (SDGs) have suggested using the per-capita Material Footprint to measure the sustainable management and efficient use of natural resources for Goal 12, which seeks to ensure sustainable consumption and production patterns. Additionally, the global indicator framework for SDGs requires indicators to differentiate between income, age, sex, race, ethnicity or other characteristics, where relevant (UN 2017). Only indicators based on micro data allow such disaggregated conclusions to be drawn from individual or household characteristics. As such, they enable researchers and policymakers to address different population and consumer groups.

In our study, private consumption has been divided into the following components:

(1) Nutrition, including diets, food waste and all foodstuffs and drinks consumed;

(2) Construction and housing, including the use of energy (electricity and heating) for household purposes;

(3) Consumer goods, including clothes, furniture, household appliances such as refrigerators and washing machines, and consumer electronics such as TV sets and tablets;

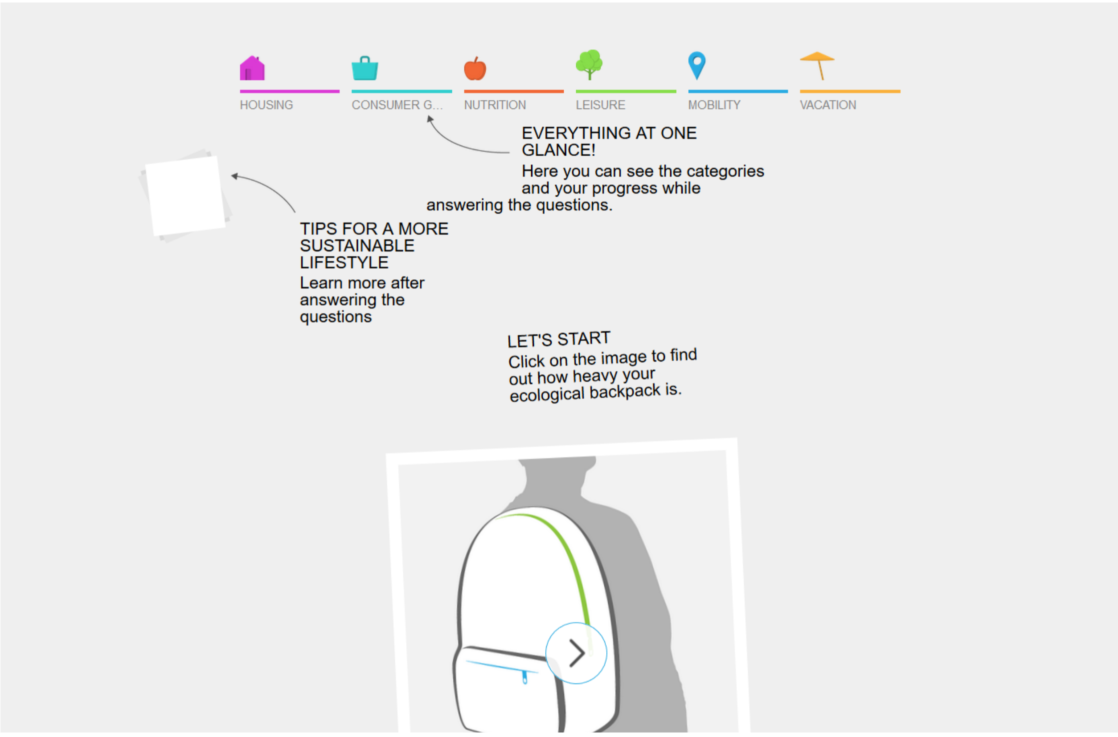
(4) Mobility, including everyday transport such as commuting and leisure activities by car, motorcycle, bicycle and public mobility;

(5) Leisure activities, including hobbies such as sports and cultural activities;

(6) Vacations, including travel and accommodation.

The Material Footprint calculator, including all questions and items, can be accessed in full at ressourcen-rechner.de/?lang=en. Figure 1 below shows the landing page of the resource calculator with its dimensions.

Figure 1. Screenshot of the Resource Calculator landing page



The online application also collects anonymised information on users' socioeconomic characteristics. Personal socioeconomic information on users includes sex, age, years of schooling according to the International Standard Classification of Education (ISCED-97, see Schneider 2008) and social status based on occupational status. Information on users' households includes data on the relative household income (net household income compared to friends), household size, the number of children living in the household, the total living area and the size of the community. Additional personal socioeconomic characteristics that entered our analysis included the willingness to pay (WTP) for environmentally friendly products and subjective well-being. We operationalised the willingness to pay of users as an item asking whether it would be acceptable for users to pay higher prices for green products on an equidistant scale from "very acceptable" to "very unacceptable". In summary, we provide personal socioeconomic characteristics (sex, age, education, occupational status, the Willingness to Pay for environmentally friendly products and individual life satisfaction) as well as socioeconomic household characteristics (household size, dwelling size, subjective household net income). We found that our sample tends to be biased towards younger, female and higher educated people than on average in Germany (see Table 1). According to the latest national census in Germany in 2011, the average age in Germany was 44 years, 51 % of the population was female and average schooling was 10 years (according to ISCED-97).

The application was advertised on the Wuppertal Institute website, by independent online blogs on sustainable living, and in reviews of economic and product testing magazines. The application can be used for free; there are no incentives involved, and participation is voluntary. A total of 68,485 people participated in the survey between its launch on 25 February 2015 and 19 December 2017. After preparing the data and removing invalid and implausible responses, information provided by 67,800 users was analysed. About 60% of the users provided additional socioeconomic information. The varying number of observations between single variables is due to implausible responses and missing data due to non-response. We censored the data on Material Footprints as well as on age, size of residence and number of children in the household at the 99th percentile. In other words, we excluded the highest one per cent of observations of the distribution in order to address outliers and implausible responses.

Table 1 provides an overview of the Material Footprints of users and socioeconomic characteristics of users which entered our analysis.

Tab 1. Descriptive statistics of the Material Footprint and selected characteristics of users

	valid.n	*mean*	*sd*	*min*	*max*
MF_overall	60647	25829.29	9992.13	2711	74788
MF_mobility	60372	6561.76	6444.02	0	40083
MF_housing	60215	8726.42	4017.14	45	27056
MF_nutrition	60204	5189.24	1342.54	0	9305
MF_consumption	60192	2703.3	1146.1	0	6862
MF_leisure	60268	486.77	709.51	0	6294
MF_holidays	60302	1547.91	1522.73	0	9442
Female (*ref.* Male)	34538	0.6	0.49	0	1
Age	34044	34.01	12.71	1	71
Education	34602	13.9	3.77	0	21
Income	33927	-0.17	1.11	-2	2
Fulltime	28183	0.64	0.48	0	1
WTP	27583	0.79	0.78	-2	2
Life satisfaction	33915	7.31	1.83	1	10
Dwelling sz.	60339	99.03	54.04	1	400
Household sz.	56095	2.57	1.27	1	7

Note: Descriptive statistics include the number of valid observations (*n*), the mean, the standard deviation (*sd*), minimum (*min*) and maximum (*max*) number of observations. “Income” measures the household net income in comparison to the household net income of friends (on a five-point Likert scale). “WTP” (Willingness to Pay) measures the willingness of users to pay higher prices for environmentally friendly products (on a five-point Likert scale) and “Life Satisfaction” measures the life satisfaction of users based on a ten-point scale.

The analysis determined that the total average material footprint is 25.49 tonnes per person. In comparison, Pothen et al. (2018) report an average Material Footprint of 26.99 tonnes per equivalised German household in 2008. Buhl et al. (2017a) reported a bigger average Material Footprint per person in North Rhine-Westphalia in 2013, between 30.99 tonnes and 31.72 tonnes. The lower Material Footprint of our analysis may come as a result of sample bias towards users with more environmentally conscious behaviour, as indicated by their willingness to pay higher prices for greener products. Furthermore, the sample may over-represent young and female participants in Germany (Buhl 2017b, Buhl et al. 2018).

2.2 Methods

In order to address our research questions, we regressed the Material Footprint according to partial Material Footprints for different arrays of consumption, personal socioeconomic characteristics and socioeconomic household characteristics, as presented in Table 1. This can also help us to account for the question of whether the influence of socioeconomic features only holds true for the overall Material Footprint, or also for any partial Material Footprint, such as leisure. For this reason, we also tested the influence of each personal or household socioeconomic predictor on the overall as well as partial Material Footprint while controlling for all other available socioeconomic inputs and partial Material Footprints in separate models. We set up the final linear OLS (ordinary least squares) model as follows: $Y = X\beta + Z\gamma + V\mu + \varepsilon$. Where Y is a vector containing the overall and partial Material Footprint; X is a vector of the partial Material Footprint (by individual component); Z are personal socioeconomic characteristics; V are socioeconomic household characteristics. β, γ, μ are vectors describing the regression coefficients. ε is the residual vector.

The partial Material Footprints are the Material Footprints for housing, mobility, nutrition, leisure, consumer goods and vacations. Personal characteristics include age, sex, education, and occupational status as well as the willingness to pay (WTP) for environmentally friendly products, and life satisfaction. Household characteristics comprise relative household net income, household size and the size of the dwelling. Relative household net income as well as the WTP have been operationalised as equidistant and thus quasi-metric Likert scales. Categorical variables such as sex and occupational status have been introduced to the model as dummy variables. This ways, the characteristics are interval data that can be interpreted meaningfully in linear regression.

From a normal quantile-quantile plot of the empirical quantiles vs. the quantiles of a standard normal distribution, we found that the distribution of error is not normally distributed and may therefore bias inferential statistics. However, as Lumley et al. (2002) showed, due to the Central Limit Theorem, inferential statistics based on *t*-tests in linear OLS regressions do not depend on normally distributed residuals if the samples are sufficiently large. The Central Limit Theorem states that, if we consider repeated sampling, the distribution of the OLS estimates of the coefficients follows a normal distribution for large sample sizes. Consequently, any non-normality of residuals does not bias the inferential statistics (i.e. *t*-test). Lumley et al. (2002) found that samples of n=100 are sufficiently large. Therefore, we chose not to transform our data into normal data due to our large sample dataset. More importantly for unbiased testing, we did not find any violations of the constant variance assumption on residuals, multi-collinear predictors or non-linear relations. Therefore, we consider linear, multiple ordinary least square (OLS) estimates to be an efficient, consistent and unbiased estimation.

3. Results

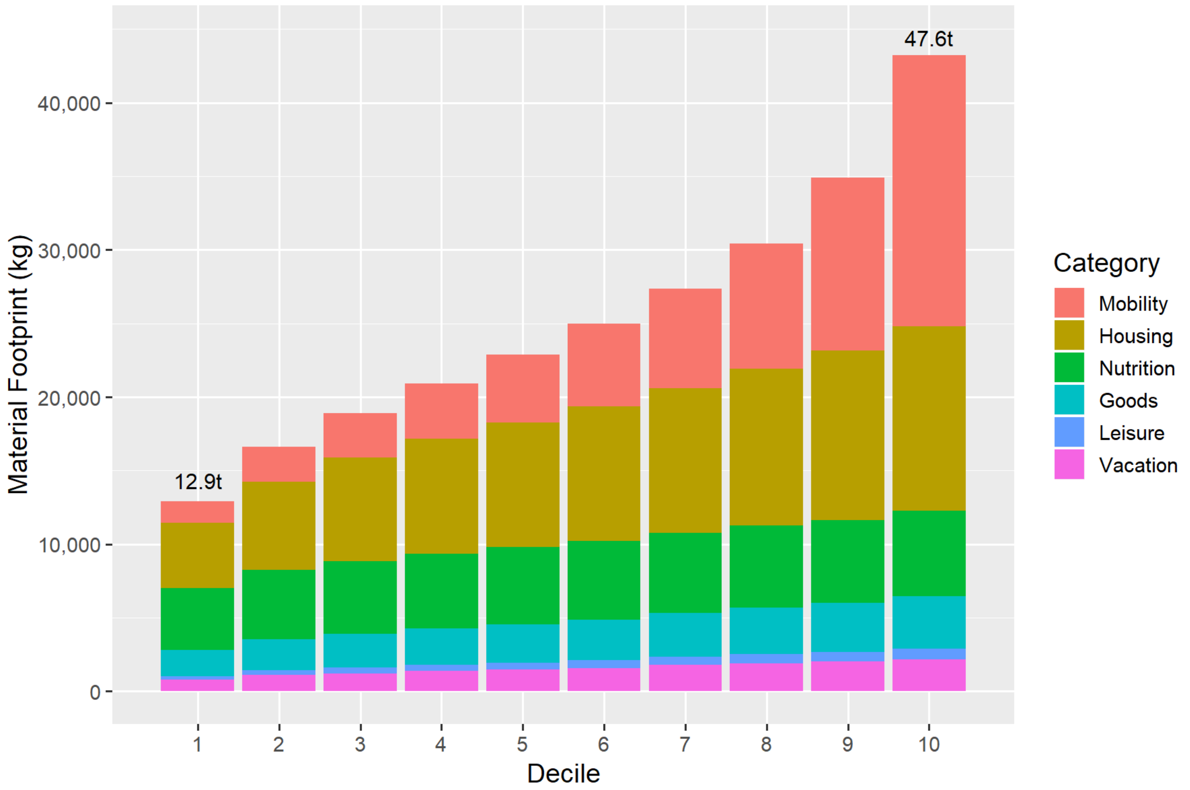
3.1 Descriptive results

First, we present the Material Footprint according to its partial components, from housing to holidaymaking. Figure 2 shows the partial footprints by decile. Buhl et al. 2018 also provide descriptive results of an earlier version of the data with less observations. More importantly Buhl et al. (2018) give no multivariate correlations and no indication of their significance, but rather present a first glance of an earlier version of the data. We, in contrast, provide multivariate findings providing test statistics of the significance of the correlations. This way, our analysis provides whether socioeconomic features influence the Material Footprint significantly and whether partial Material Footprints correlate significantly to each other.

Decile 1 represents the 10% of users with the smallest overall Material Footprint. Decile 10 represents the 10% of users with the highest overall Material Footprint. Mobility, housing and nutrition make up the biggest footprints across all deciles. However, while the Material Footprints for housing and nutrition do not differ relevantly between deciles, the

Material Footprint for mobility increases significantly as deciles increase. The Material Footprint for mobility seems to better differentiate users than housing or nutrition since the variance in mobility seems to be higher between respondents than in housing or nutrition. Notably, the smallest user decile exhibits a Material Footprint that is 73% smaller than that of the highest decile.

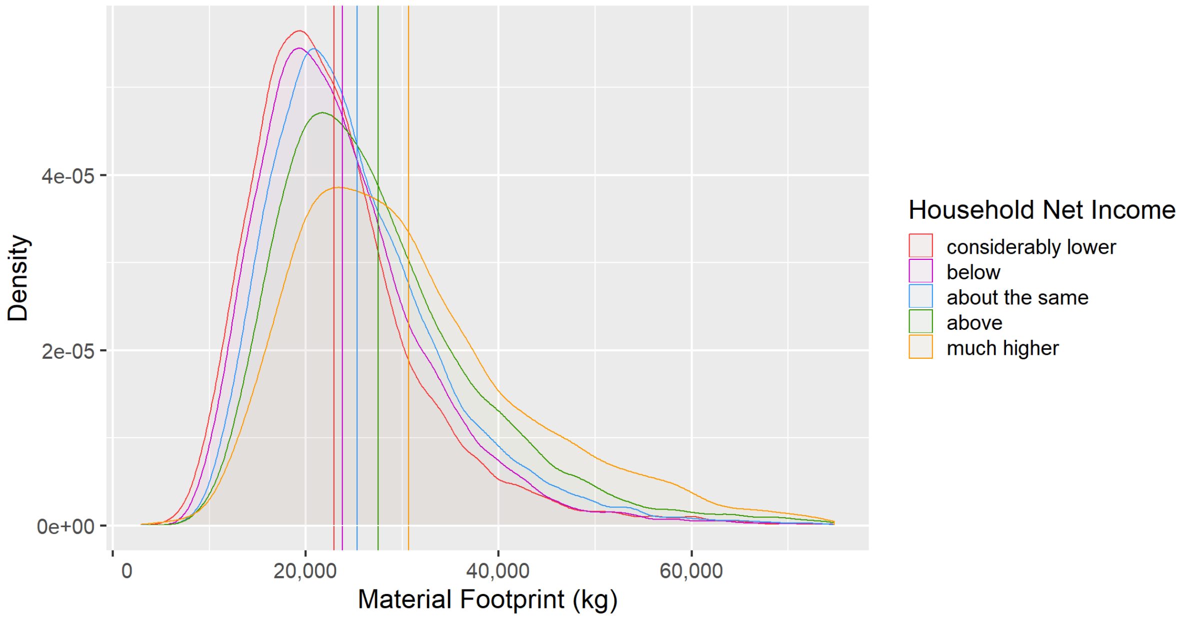
Figure 2. Material Footprint by deciles



Note: Decile 1 represents the 10% of users with the smallest overall Material Footprint; Decile 10 represents the 10% of users with the biggest overall Material Footprint.

The Material Footprint grows as income increases (Figure 3). The vertical lines are the mean Material Footprint for each income group. The distribution of the Material Footprint of users with considerably lower income is highly left-skewed. People with income considerably lower income predominantly show relatively small Material Footprints, and only a few exhibit very big Material Footprints. In contrast, the distribution of the Material Footprint of people with much higher income shows more users with bigger Material Footprints. People with high income demonstrate less skewed and more fairly distributed Material Footprints from small to large. We hypothesise that users who state that they have a higher household net income have bigger Material Footprints (see also Buhl et al. 2018).

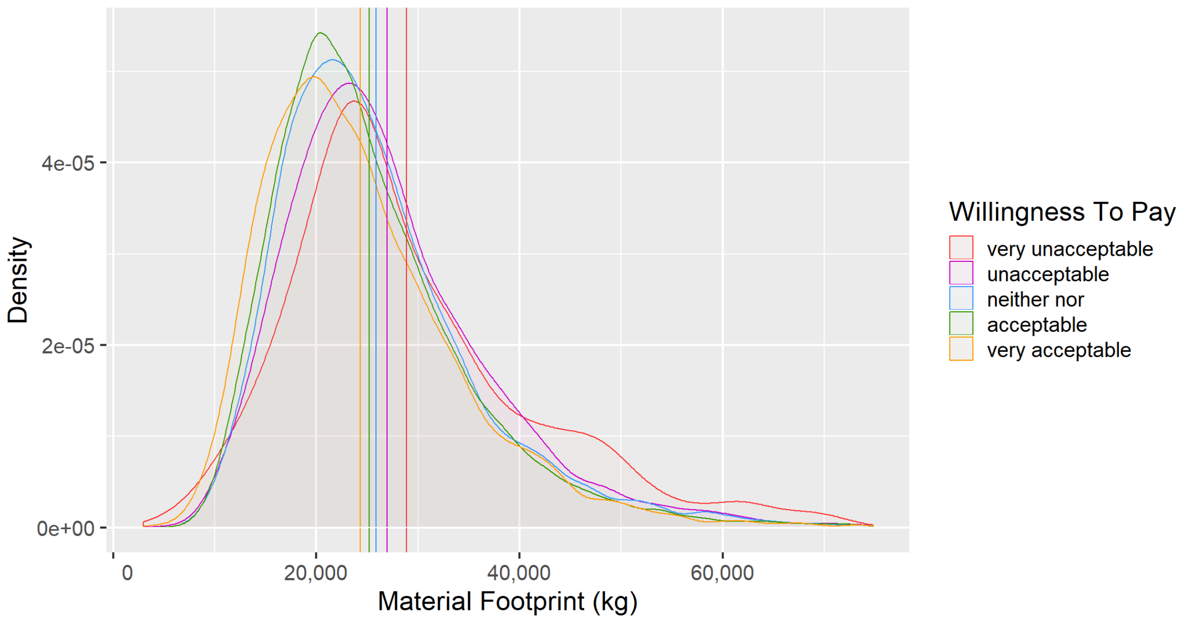
Figure 3. Material Footprint by relative household net income



Note: "Household Net Income" is the relative household net income measured on a five-point scale from a "considerably lower" to a "much higher" income compared to the household net income of friends. The vertical line is the mean.

Figure 4 shows that the overall Material Footprint decreases with the user's greater willingness to pay. The figure shows that the distribution of the Material Footprint of users who consider paying higher prices for environmentally friendly products to be very unacceptable shifts to the right in comparison to users who find it more acceptable to pay higher prices. Moreover, the density plot reveals that users who found paying higher prices to be "very unacceptable" were more likely to demonstrate large Material Footprints above 40 tonnes per year. We hypothesise that users' willingness to pay for environmentally friendly products decreases the size of their Material Footprint.

Figure 4. Material Footprint according to the willingness to pay for environmentally friendly products

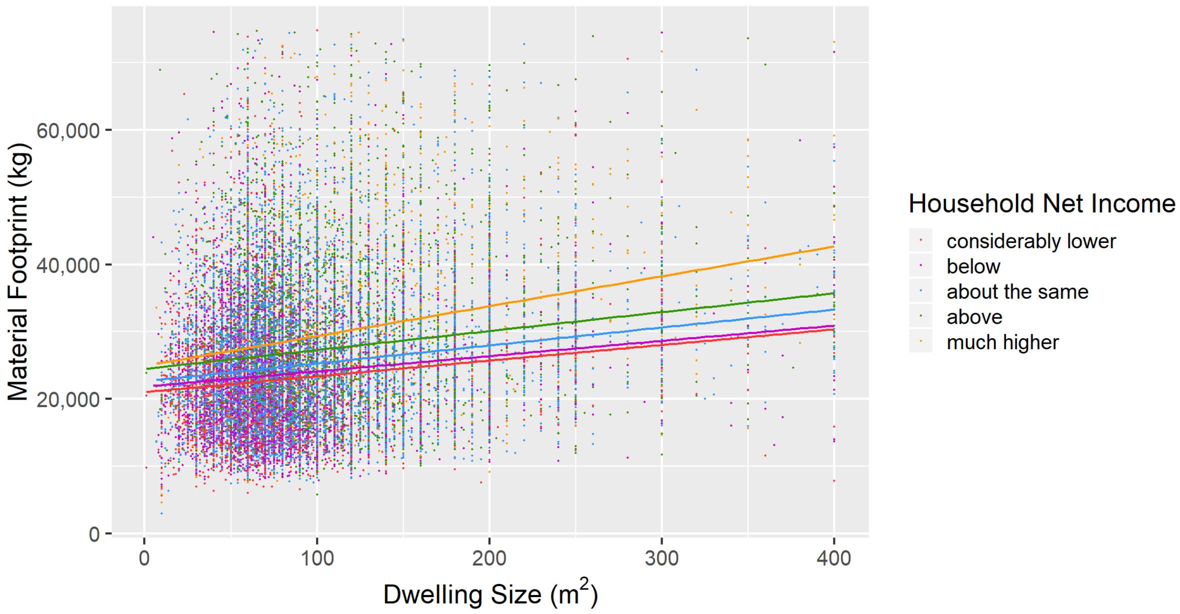


Note: "Willingness To Pay" is the willingness to pay (WTP) higher prices for environmentally friendly products measured on a five-point scale from "very unacceptable" to "very acceptable". The vertical line is the mean.

Figure 5 shows the scatter and linear trend between users' dwelling size (m^2) and their overall Material Footprint. In addition, people's Material Footprint grows as their size of dwelling increases. The reason for this may be twofold. First, the size of dwelling represents users' standard of living, which may exhibit an overall higher use of natural resources across arrays of consumption. Second, an increased dwelling size requires higher levels of upkeep and maintenance in terms of heating energy and lighting.

Moreover, the data points in the scatter plot are coloured by relative household net income. The scatter shows that users who state that their household net income is considerably lower than average (red dots) report smaller dwelling sizes and smaller overall Material Footprints than users with average, above or much higher household net incomes (blue, green and orange dots).

Figure 5. Material Footprint vs. size of dwelling



Note: “Household Net Income” is relative household net income measured on a five-point scale from “considerably lower” to “much higher”.

However, in order to test whether the positive effect of dwelling size on the overall Material Footprint is influenced by any third predictors, such as income, we conducted a multivariate regression analysis.

3.2 Multivariate results

We ran 13 regression models. Seven models regressed the overall Material Footprint on users' socioeconomic characteristics. Another block of six models regressed the partial Material Footprints on each other, while controlling for socioeconomic characteristics in order to test whether and how Material Footprints for different arrays of consumption correlate. We did not regress the overall Material Footprint on its partial Footprints due to perfect collinearity; the partial Material Footprints perfectly explained the overall Material Footprint. The fact that mobility, housing and nutrition are key inputs in the overall Material Footprint has already been shown by Buhl (2014) and Watson et al. (2013). We thus concentrate on the question of whether resource use in one array influences resource use in another, and vice versa. For instance, we contemplated whether bigger Material Footprints for housing correspond to smaller Material Footprints for holidaymaking.

The results in Table 2 show that the Material Footprint for mobility correlates positively with nutrition, consumer goods and vacations, but does not correlate significantly with housing and leisure. In contrast, housing does not correlate with mobility, but positively with nutrition, consumer goods as well as leisure, and negatively with vacations. Nutrition correlates positively with all other footprints. Consumer goods correlate positively with all other footprints except holidaymaking, most strongly with housing. Leisure correlates positively with nutrition, consumer goods and vacations. Holidaymaking correlates positively with mobility, nutrition and leisure, but negatively with housing.

The strongest effect of consumption on housing may come from the fact that appliances and household equipment significantly affect electricity consumption. The single negative correlation between holidaymaking and housing may be explained by users who travel more often and who do not consume heating energy and electricity at home.

However, the explained variance in footprints only slightly increases when considering partial footprints in addition to socioeconomic characteristics. The socioeconomic characteristics explain the Material Footprints better. In the following, we thus report the results of the models controlling for socioeconomic characteristics in different footprint arrays without the controls for partial footprints.

Female users exhibit a smaller Material Footprint than male users, except for when it comes to housing. Older users have a bigger footprint for nutrition and consumer goods, but smaller footprints for housing, mobility, leisure, vacations and overall. Higher educated users exhibit smaller footprints, except for mobility and vacations. Users who reported higher household net incomes have bigger footprints, except for housing. Recent studies on representative sampling in Germany corroborate the finding that higher household net income comes with increasing Material Footprints (Buhl 2014, Buhl and Acosta 2016a,b, Ottelin et al. 2018). Users who work full-time exhibit bigger mobility and consumption footprints, but smaller nutrition and leisure footprints. Users with a greater Willingness to Pay (WTP) for environmentally friendly products and services have smaller footprints, except for vacations. Users with a higher level of life satisfaction have bigger footprints for vacations and leisure, but smaller overall footprints and smaller footprints for housing, nutrition and consumer goods. Buhl et al. (2017b) have presented a more elaborate model on the influence of resource use on subjective well-being, coming to the same conclusion of no significant correlation between users' Material Footprint and life satisfaction. Users who live in larger dwellings generally have bigger Material Footprints for all arrays. Users living in larger households, however, have smaller overall Material Footprints, and smaller footprints for housing, mobility, consumer goods and vacations, but bigger footprints for nutrition.

Tab. 2. Results from multiple regression analysis

	Dependent variable:												
	MF_overall	MF_housing		MF_mobility		MF_nutrition		MF_consumption		MF_leisure		MF_holidays	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
MF_mobility			0.004				0.01***		0.01***		0.0004		0.02***
MF_housing					0.01		0.03***		0.06***		0.004***		-0.02***
MF_nutrition			0.17***		0.34***				0.06***		0.03***		0.05***
MF_consumption			0.98***		0.46***		0.15***				0.04***		-0.002
MF_leisure			0.09***		0.04		0.11***		0.06***				0.28***
MF_holidays			-0.09***		0.27***		0.03***		-0.001		0.05***		
female (*ref.* male)	-1,575.58***	378.92***	598.85***	-881.91***	-608.30***	-604.24***	-569.34***	-83.69***	-51.84***	-147.24***	-118.97***	-23.10	68.70***
age	-36.75***	-19.44***	-21.35***	-9.90***	-10.96***	6.35***	8.26***	1.15***	2.60***	-9.25***	-8.90***	-4.20***	-2.32***
education	22.52	-112.03***	-78.74***	134.62***	141.82***	-13.91***	-9.74***	-23.74***	-16.29***	-5.48***	-5.84***	52.44***	51.33***
income	1,285.03***	84.60***	14.40	756.15***	648.26***	96.26***	63.43***	59.60***	39.27***	33.98***	20.01***	169.06***	137.94***
fulltime	1,416.95***	1.76	-2.46	1,415.46***	1,377.68***	-30.52*	-49.26***	31.50***	29.63***	-40.28***	-38.08***	37.08*	29.29
WTP	-1,125.90***	-540.50***	-376.19***	-100.73**	59.16	-300.87***	-268.40***	-101.20***	-46.63***	-27.65***	-12.42**	30.95**	46.41***
life satisfaction	-43.67	-111.81***	-75.39***	12.19	7.46	-15.21***	-12.74***	-26.10***	-20.61***	19.54***	17.68***	69.58***	62.53***
dwelling sz.	82.56***	42.84***	33.25***	19.63***	13.26***	3.63***	0.77***	8.30***	5.36***	1.41***	0.65***	1.91***	1.97***
household sz.	-3,553.74***	-2,108.18***	-1,323.69***	-449.25***	-72.30	14.98*	197.63***	-763.06***	-635.19***	-17.53***	22.10***	-45.42***	-80.82***
Constant	28,768.59***	12,953.68***	7,476.09***	4,018.74***	-188.81	5,442.92***	4,247.97***	4,429.26***	3,248.30***	753.08***	322.61***	453.28***	183.02*
Observations	24,806	24,680	24,157	24,718	24,157	24,669	24,157	24,676	24,157	24,689	24,157	24,729	24,157
R^2	0.24	0.34	0.38	0.07	0.08	0.13	0.15	0.52	0.55	0.06	0.07	0.05	0.07
Adjusted R^2	0.24	0.34	0.38	0.07	0.08	0.13	0.15	0.52	0.55	0.06	0.07	0.05	0.07
Residual Std. Error	8,367.22 (df = 24796)	3,183.30 (df = 24670)	3,046.56 (df = 24142)	6,172.88 (df = 24708)	6,100.99 (df = 24142)	1,211.18 (df = 24659)	1,190.29 (df = 24142)	783.23 (df = 24666)	747.06 (df = 24142)	628.44 (df = 24679)	614.77 (df = 24142)	1,495.51 (df = 24719)	1,474.38 (df = 24142)
F Statistic	856.66*** (df = 9; 24796)	1,437.29*** (df = 9; 24670)	1,056.36*** (df = 14; 24142)	202.48*** (df = 9; 24708)	150.18*** (df = 14; 24142)	409.67*** (df = 9; 24659)	313.56*** (df = 14; 24142)	2,914.85*** (df = 9; 24666)	2,131.03*** (df = 14; 24142)	164.84*** (df = 9; 24679)	135.86*** (df = 14; 24142)	136.44*** (df = 9; 24719)	124.09*** (df = 14; 24142)
Note:	*p<0.1; **p<0.05; ***p<0.01;'MF“ is Material Footprint												

4. Discussion and conclusion

We contemplated whether socioeconomic characteristics influence consumers' Material Footprint, and how the influence differs between arrays of consumption, from housing to holidaymaking. To this end, we analysed user data from an online footprint calculator. The average Material Footprint of users of the calculator is 26 tonnes per year, which is below comparable Material Footprint calculations based on representative data for Germany. This difference may be due to the fact that the sample of people who chose to use the resource calculator exhibit more pro-environmental behaviour than the general public as a whole. Although the data presented shows a high variance in terms of socio-economic characteristics well our sample tends to biased towards younger, female and higher educated people than on average in Germany. The overall Material Footprint of users may also be biased by predictors which may significantly contribute to resource use, but are not yet covered by the tool (e.g. awareness of sustainable lifestyle options or accessability to services). In addition, the life cycle assessment of products and services covered by the calculator may also be subject to improvement and thus bias the results further. The most important limitations in this regard are assumptions that are used to fill the gaps from the consumer input (e.g. assuming a typical middle-class car rather than a specific brand or model) and scaling effects from shared areas of consumption (e.g. assuming that every member of the household consumes the same amount of electricity). The calculations therefore reflect a person with similiar consumption patterns rather than a certain individual. Further research will focus on improving the robustness of the calculations, identification of the most relevant consumer inputs for both overall footprints and footprint differences and further disaggregating the results of the footprint into different raw material groups (e.g. preciouse and non-precious metal use for vehicles as shown in Teubler et al. 2018).

As well, future research on footprint calculators could be improved by more representative sampling in terms of sex, age, education as well as further socio-psychological characteristics like environmental preferences. For instance, the footprint calculator could be instrumented in national, more representative, environmental monitoring surveys on private resource use.

Nevertheless, our results are based on a large sample consisting of 67,800 German users who calculated their Material Footprint between February 2015 and December 2017. We ran 13 regression models in order to reveal the influence of socioeconomic characteristics such as age, sex, income and the size of dwelling as well as correlations between the Material Footprints from housing to holidaymaking. Depending on whether users provided information on their socioeconomics, our regression models made use of between 27,906 and 28,639 user profiles.

Our results have shown that users' Material Footprints mainly correlate positively. Having a bigger Material Footprint in one array of consumption goes hand in hand with a larger Material Footprint in other arrays, except for housing and holidaymaking: The higher the resource use on vacations, the lower the resource use at home.

In most cases, users' socioeconomic characteristics have a significant influence on their Material Footprints. However, this influence varies by the array of consumption. For instance, older users reveal bigger footprints for nutrition and consumer goods, but smaller footprints for housing, mobility, leisure, vacations and overall. Users who live in larger households exhibit smaller overall Material Footprints, and smaller footprints for housing, mobility, consumption and vacations, but bigger footprints for nutrition. Only when it comes to income and the size of dwelling do users show generally bigger material footprints for all arrays. Future research should account for potential interaction effects of socioeconomic characteristics on the Material Footprint. For instance, pro-environmental behaviour could decrease the effect of household income on the Material Footprint. As well, the younger users may show pro-environmental preferences more often and thus reinforce the effect of preferences on the Material Footprint.

5. Policy Implications

Our results suggest in line with the literature that addressing the income of consumers, *e.g.* in terms of a tax depending on the material input per product or service could result in lower resource use of private consumption in all consumption categories. Increasing pro-environmental preferences of consumers may as well reduce the overall personal Material Footprint and the Material Footprint in almost all consumption categories, except the Material Footprint for holidaymaking. As well and more generally, it should be noted, that increasing the educational attainment of consumers may result in decreased Material Footprints, but not in terms of resource use for mobility and holidaymaking. As a result, educational attainment does not influence the overall Material Footprint of users.

This finding highlights that differentiating the influence of socioeconomic characteristics along consumption categories delivers a more accurate picture of the socioeconomic effects on resource use. Focusing on the effects on the aggregated overall Material Footprint may result in misleading findings. For instance, specific socioeconomic characteristics may not exhibit any effect on the overall Material Footprint while actually it does influence the Material Footprint in specific arrays of consumption.

As proposed by the indicator framework for the Sustainable Development Goals (SDGs), indicators should be disaggregated, where relevant, by income, sex, age, geographic location, or other characteristics, where relevant. Our results show that users' Material Footprints differ significantly depending on their socioeconomic characteristics. We suggest that indicators monitoring the SDG 12 on sustainable consumption and production patterns, in particular on the sustainable management and efficient use of natural resources, should differentiate population segments by socioeconomic characteristics. The same accounts for national programmes such as the National Programme on Sustainable Consumption in Germany that strive to monitor the implementation of the SDGs. They should therefore consider indicators based on survey and life cycle data that is possible to disaggregate the Material Footprints directly according to socioeconomic characteristics from a single data set. In this way, we consider our footprint calculator to be the only instrument to this point, being able to differentiate private resource by socioeconomic characteristics based on survey and life cycle data. In this respect, our analysis of the data is one of very few studies that presents distributions of Material Footprints according to socioeconomic characteristics based on a large sample. Material Footprint analysis so far, either presents macro based analysis of national material flows or linking such material flows (based on input/output models) with national surveys on expenditure data rather than direct measurements of the resource use in private households.

Consequently, we conclude that policy proposals would be better informed by taking survey studies into account which differentiate between population groups in different consumer policy arenas such as nutrition or mobility and directly measure the resource use of private consumption. As well, instruments like footprint calculators could be designed more effectively giving feedback to different population groups. Feedback can be given to users directly with respect to high Material Footprints in specific areas combined with the information available on users. For instance, younger users with relatively high resource use in consumer goods and consumer electronics respectively may be addressed by their preference for consumer electronics. Older users with relatively high incomes, living in large dwellings may be given feedback on retrofitting housing solutions. In this respect, we suggest that improvements of survey instruments in footprint calculators should focus on a more elaborated integration of items that differentiates better according to socio-psychological features of users, *e.g.* in terms of lifestyle.

Further, such feedback may take into consideration potential spill over effects. Feedback may be given in areas which correlate negatively with Material Footprints in other areas in order to increase the effectiveness of actions rather than triggering effects which are cancelled out (due to rebound effects).

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