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Small is beautiful? Stories of carbon footprints, socio-demographic trends and small households in Denmark

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ABSTRACT

Shrinking household size is a key challenge for sustainability, simultaneously decreasing sharing and increasing resource consumption. We use the Danish Household Budget Survey and carbon intensities from EXIOBASE to characterise small households in socio-demographic cohorts along the carbon footprint spectrum. Single and dual occupant households represent 77% of the Danish carbon footprint and 73% of the sample, making these households highly relevant for climate and social policy. We identify high carbon footprint cohorts to determine potential intervention targets such as wealthy males living alone and couples in suburban areas. To add emotional depth to these characteristics we provide three stories to our results. Illuminating characteristics of high impact households provides a foundation from which to design and implement interventions to reduce the carbon consequences of the growing trend towards living alone. We also characterise low carbon footprint cohorts, with specific focus on the effects of low income, disability, energy poverty, and population density. Our study makes an original contribution using storytelling, a step in the direction of increasing empathy and compassion for the various carbon footprint cohorts and working toward socially and environmentally sustainable futures.

1. Introduction

Human population has introduced wide ranging and often negative consequences for the natural environment [1]. Population stability and decreasing fertility have thus been heralded as promising to reduce greenhouse gas (GHG) emissions [2–4]. However, household size has been decreasing steadily in both developed and developing countries, at an accelerating pace since the 1980s [5]. The European Union (EU) leads this trend; in 2017, 32.5% of households consisted of single occupants [6] and almost 46 million Europeans are predicted to live alone by 2025 [7]. Globally, intergenerational living is decreasing [8] and one-person households are expected to be the most numerous household type worldwide by 2030 [9]. Shrinking household sizes worldwide [10] is one among a myriad of social and economic trends, which have been linked to negative carbon consequences, including rising affluence and economic growth [11], strong reliance on fossil fuels for energy [12], and urban sprawl [13,14] among others. While there may be multiple socio-demographic factors that are important for the size of carbon footprints, here we focus on the characteristics of small households and their carbon contribution.

The growing number of households is a fundamental challenge to dramatically reducing resource consumption in order to mitigate human impact on the environment [15,16], and avoid catastrophic climate change. Households make up a major share of global consumption [17], and household dynamics and practices will need to change in order to meet equitable climate targets [18]. The single occupancy trend is paralleled by an increasing demand for more living space for single occupants, leading to an increasing dwelling space per person and more resource use for the construction of residential property [19,20]. The scale of consumption largely depends on occupant practices [21]. For example, households living in identical buildings can consume three times as much energy as their neighbours [22]. Practices performed within households, e.g. cooking and washing, are also increasing, further accelerating domestic consumption of water and energy [23], despite - or sometimes due to - more efficient technology [24]. These everyday practices can benefit from economies of sharing: when people live together, they tend to share laundry, meals and common heated or cooled areas [10]. The number of occupants thus has a significant

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impact on consumption [13,25,26]: for example, analyses of European descriptive statistics show that four to five people living together on average consume half as much energy per capita as single occupants [10,27]. Single occupant households also have more food waste – an estimated 45% more food is wasted in single occupant households compared to the average larger household [28,29]. Household sharing brings about the strongest per capita energy and GHG emission reductions in the context of housing (e.g. electricity use, materials, waste and water services, fuel consumption) and food [10]. Despite evidence that decreasing household size has significant sustainability implications, research and policy still emphasise smart technologies and buildings, which on its own is insufficient to curb increasing household consumption [30]. Trends of shrinking households pose a challenge to reaching other sustainable goals worldwide, including achieving well-being outcomes such as basic education and safe water [31].

Despite increasing evidence on how various socio-demographics affect carbon footprints and energy use [13,32,33], it is unclear how prevalent these trends are among small households and what their environmental implications are. Small households (single and dual occupant) are a heterogeneous group consisting of people with substantially different demographic and socio-economic characteristics, which calls for a more nuanced approach to policy. Small households are a growing environmental challenge and thus increasingly relevant for energy and environmental policy, and more research is needed to understand how the characteristics of this cohort affect consumption.

2. Research design: carbon footprint calculations and storytelling

To explore questions around decreasing household size and carbon footprints, Denmark provides an interesting case for three reasons. Firstly, Denmark has particularly high single occupancy rates at nearly 40% nationwide and 50% in the Danish capital, Copenhagen [6], and in-line with the EU, Denmark's housing sector is responsible for a third of final energy consumption [34]. Secondly, Denmark is a front-runner in the second demographic transition [35,36]: the biggest reductions in household sizes occurred several decades ago and now these trends are actually slowing down compared to other countries of much higher average household size. Finally, Denmark has some of the highest income levels, ranking tenth in the world in terms of GDP per capita in constant prices [37]. At the same time, rich Danes have a relatively low carbon intensity compared to other high income cohorts in European countries [38]. Denmark is also the second happiest country in the world [39], and a high scorer on the human development index [40], although lagging in the happy planet index [41]: deficient environmental progress in the context of socially progressive society has been labelled the "dark side" of the Nordic model [42]. Using Denmark, a front runner in small households to explore consumption implications of the global trend toward living alone is thus promising for informing policy for social *and* environmental sustainability in understanding global carbon challenges.

To explore the Danish case we use a methodological bricolage [43] consisting of carbon footprint calculations, multivariate regression and storytelling, guided by the principles of novelty, rigor, and style [44]. The diverse data collection and analysis helps to create a multifaceted understanding of our case, to emphasise both the numbers and narratives around the trend toward small households.

2.1. Carbon footprint calculations

We base household carbon footprint estimates on household expenditure data from the Danish Household Budget Survey (HBS) and carbon intensities from EXIOBASE. Both data sources reflect trends in 2010, which is the latest available Eurostat survey wave at the time of writing of this article. Since 2010 there are some indications of a stabilising trend of average household sizes. In fact, although some small reductions in household sizes have been registered between 1995 and 2016, the average household sizes stayed roughly at 2.2 members per household (author calculations based on population and household statistics by Statistics Denmark [45]).

The Danish HBS collects consumption (based on 2-week consumption diaries) and socio-economic information from 2,484 households with a response rate of 42.3% [38]. The HBS further include interviews, which collect basic information about regular expenditure, the households and their members [46]. The Danish population register was used in the sampling, where the sample was drawn randomly within a specific geographic area controlling for relevant characteristics. The survey aims to measure private household expenditure, excluding households living in small islands and other remote geographical areas [46]. The *household* is the main recording unit defined by number of occupants, spending and income [46]. The Danish HBS records household expenditure based on Eurostat's Classification of Individual Consumption by Purpose (COICOP). We applied survey household weights to ensure a representative sample in our analysis. Weighting improves the quality of the survey data as it corrects for non-response compared to register-based information about the concerned address [47]. The weighting process for Denmark takes into account the income, type of ownership of the accommodation, socio-economic grouping, the composition of the household and degree of urbanisation [47].

Fig. 1 describes the harmonisation procedure between the HBS and EXIOBASE sources. Firstly, we compared and bridged expenditure from the HBS and EXIOBASE on a country level in EUR purchaser prices. The supplementary datasheet presents the consumption bridge for the conversion from COICOP classification to EXIOBASE's 200 products. We optimised the bridge to minimise the difference between the estimated HBS expenditure in EXIOBASE product classification and EXIOBASE's actual household expenditure vector (cf. prior studies adopting this approach [10,38,50]). We also proportionately re-allocated under- and over-reporting of expenditure compared to EXIOBASE (and hence the National Accounts) to the households in the HBS. Finally, we transformed the HBS household expenditure (already in EXIOBASE classification and accounting for under- and over-reporting) from purchaser to basic prices.

Regarding the carbon intensities, we apply the global warming potential (GWP100) metric to convert various greenhouse gases (carbon dioxide, methane, nitrous oxide and sulphur hexafluoride) to kilograms of CO_2-equivalents per year and compare carbon footprints among households. We quantify indirect (i.e. supply chain) carbon multipliers for each of the 200 products directly from EXIOBASE in CO_2-equivalents/EUR, which reflect the carbon intensity of Danish consumption. We also quantify direct (i.e. fuel combustion directly from the household) carbon multipliers by sectors, reflecting the direct household emissions of Danish households. When coupled with the expenditure data, this gives the direct carbon footprint of households associated with combustion of fuel for heating and transport, and the indirect or embodied carbon footprint of households associated with the supply chains of the products consumed by Danish households. More detail on the approach and data can be found elsewhere [10,38,46].

2.2. Multivariate regressions and other social indicators

In addition, we utilise socio-economic variables available through the Danish HBS with implications for carbon footprints. Prior literature identifies all of the variables in our model as relevant to explain differences in energy needs, energy use and associated carbon footprints (e.g. [11,26,32,33,50,51]).

We explore social trends within small households (single and dual occupant households), including income, sex and age distribution, and population density. The household net disposable income is measured in EUR per capita, including monetary net income and income in kind from employment or non-salaried activities. The age variable contains six age categories, while the population density has three categories: dense, intermediate and rural (see Table 1 for more detail on the category

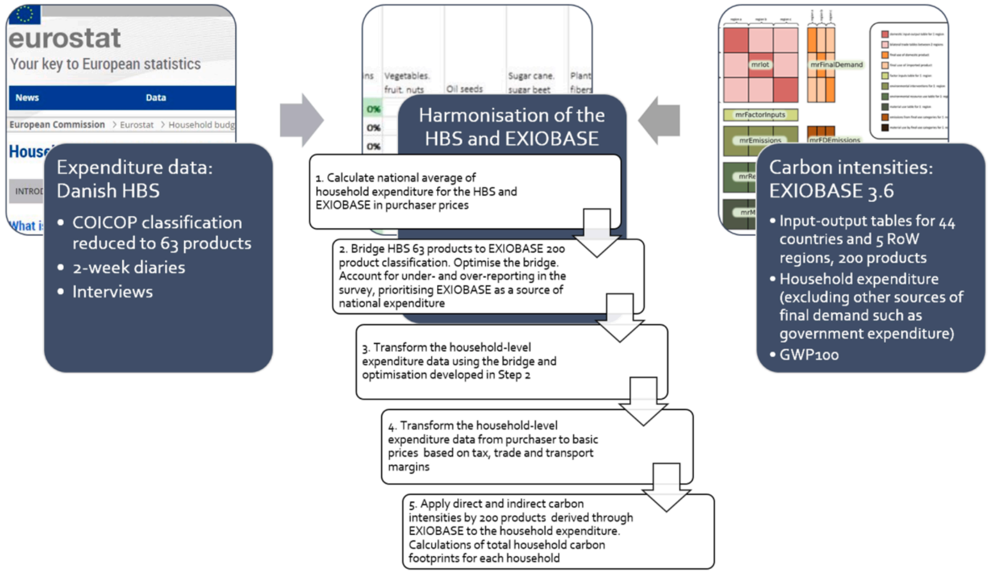

Fig. 1. Method for carbon footprint calculations. The included images for the HBS and EXIOBASE are from external sources [48,49].

Table 1
Distribution of the one-person, two-person and total DK samples by various socio-economic characteristics. All values are in %s, except for the average income measured in EUR per capita. The official statistics column compares with the total sample average unless otherwise specified. (a) We compared the top cut-off points of the Danish income deciles according to Eurostat with the threshold used in our analysis to estimate the share of the population by income bracket. (b) 2014 data. (c) See section 2.2 for definitional concerns around disability. (d) Energy poverty in the official statistics is measured as a high share of income towards energy expenditure. (e) 2020 data.

Distribution by main variable	Variable levels	1-person households	2-person households	Total sample	Official statistics 2010
Household size	Number of households by household size (share)	39.8	32.9	–	1-person: 38.7 2-person: 32.9 [45]
Income	Average net income per capita in EUR	€28,900	€29,100	€27,200	€26,900 [67]
	<€20,000	34.3	33.6	37.1	>30[a] [68]
	€20,000-30,000	31.2	29.4	32.3	
	€30,000-40,000	16.2	17.7	15.8	
	>€40,000	18.3	19.3	14.9	>10[a] [68]
Main source of income	Wage or salary	41.5	55.8	58.8	69.1[b] [69]
	Income from self-employment or property	3.7	3.0	3.3	2.2[b] [69]
	Pension or retirement benefits	44.5	35.6	29.8	15.7[b] [69]
	Unemployment or other benefits	10.3	5.6	8.1	13.1[b] [69]
Sex	Share of households with one female	53.8	91.8	60.7	1-person: 53.1 [45]
	Share of households with more than one female	0	5.3	20.0	
	Share of households with one male	46.2	91.9	56.9	1-person: 46.7 [45]
	Share of households with more than one male	0	2.8	19.2	
Marital status	Share of one or more single people	46.7	30.3	55.8	
	Share of one or more people that are married or in registered partnership	5.0	67.0	45.1	2-person: 61.9 [45]
	Share of one of more widowed or divorced people	48.0	12.9	26.3	
Age	Share of households with at least one person aged from 0 to 15	0	8.2	31.5	1-person: 0 [70]
	Share of households with at least one person aged from 16 to 24	10.0	11.0	17.3	1-person: 9.2 [70]
	Share of households with at least one person aged from 25 to 64	54.5	71.6	72.2	1-person: 53.1 [70]
	Share of households with at least one person aged 64+	35.5	35.8	26.5	1-person: 37.7 [70]
Population density	Densely populated (>500 inhabitants/km^2)	44.9	35.2	37.8	34 [71]
	Intermediate (100–499 inhabitants/km^2)	16.7	18.8	18.3	21 [71]
	Sparsely populated (>100 inhabitants/km^2)	38.4	46.0	44.0	45 [71]
Disabled household member	Yes	9.1	3.4	5.5	15-18[c] [72]
	No	90.9	96.6	94.5	82-85[c] [72]
Living in energy poverty	Yes	19.8	12.5	14.4	17.9[d] [53]
	No	80.2	87.5	85.6	82.1[d] [53]
Living with children	Yes	0	8.1	24.3	28.3[e] [73]
	No	100	91.9	75.7	71.7[e] [73]

levels). While studies commonly use education in household socio-demographic characterisation, there was no information on the level of completed studies by household members in the HBS. Furthermore, the education effect on carbon footprints tends to be small and mixed, varying across countries [32,33].

We also capture trends around disability and energy poverty and explore their energy and carbon implications in the context of small Danish households. This is to allow for a more nuanced approach to environmental policy, taking into account social and energy need differences when planning and delivering interventions as a matter of effectiveness and social justice [50]. For example, disabled people may have higher energy requirements associated with indoors heating, access to equipment and private vehicle [50]. While the HBS does not collect information on disability specifically, it collects data on current activity status of household members, including an option for permanent mental or physical disability as a reason for economic inactivity (cf. [50] for a more detailed analysis on the energy use and needs of disabled people). This definition excludes disabled people who are economically active (e.g. working or unemployed and looking for employment) or economically inactive fitting other inactivity status (e.g. children, retired or in full-time education). Thus, our article presents a very narrow definition on disability defined by activity status. However, this definition likely includes some of the most disadvantaged and excluded disabled people with more severe levels of impairment preventing them from participating in the labour market. Energy poor households are unable to afford an adequate level of energy services [52]. In this paper, energy poor households spend more than 10% of their household income on energy costs, while having an income level below the national median level. Energy poor households likely have high energy bills due to poor thermal and energy efficiency, and may have relatively low incomes and ill health [52,53].

We perform a positioning analysis, where we first quantify the carbon footprint share associated with certain cohorts of various household sizes. Second, we perform a multivariate regression analysis applying household weights for each of the single and dual household cohorts. The dependent variable in the model is per capita carbon footprint measured in kgCO_2eq/cap in logarithmic form. The independent variables in the models are included in Table 1. Third, we disaggregate the total carbon footprint associated with single and dual occupants on various cohorts based on the statistically significant social indicators. In the disaggregation of results, we ensure that each cohort represents at least 30 households.

2.3. Storytelling

Scientific facts need stories to bring them to life: especially when building emotional connections to facilitate sustainability transitions [54] and policy [55]. Everyone, policy makers included, learns about, and forms responses to, climate change by engaging with narratives. In dealing with energy consumption, storytelling has been shown to help see things differently, increase participation and inclusion, and deepen empathy ultimately leading to collective agenda settling for policy action [56]. In this paper we use stories as a communication strategy to nurture understanding and empathy for various carbon footprint cohorts identified in our quantitative analysis, useful for those trying to intervene into the myriad of socio-material factors leading to high consumption everyday life. Such an approach could also address low impact households in designing of energy policy, making sure that everyone's energy needs are met.

To explore the human stories behind the numbers we use our own experiences of Danish culture inspired by traditional and digital ethnography [57], speculative fabulation or SF[1] [58] as well as a host of literature calling for storytelling in energy research (cf. [59–61]) to create observation-based narratives. Using stories is an experiment with the hope to increase the understanding, uptake and influence of the numbers behind consumption impacts of demographic characteristics to inspire holistic social and environmental sustainability transitions.

Our observations are based on participation in Danish everyday life. Since 2009 we, two non-Danes, have spent regular periods of time in Denmark, and used facebook, twitter and instagram to keep in touch with Danish friends and acquaintances and are thus exposed to their everyday life, updates, photographs and thoughts. As an added layer, during writing this paper we also read qualitative energy use research interviews from other projects and energy use research papers based in Denmark. This three-pronged ethnography: diving into everyday life, social media and scientific research [22,62,63], provides us with a multifaceted understanding of Danish culture that we then apply to three high impact cohorts identified by our statistical data. Our results include three stories based on our observations to give our numbers an imaginative outlet, and to inspire ambitious thinking about future interventions and sustainability potentials.

Each of our stories is not based on a particular individual, but rather the sum of experiences of our Danish participant observations. As an extra measure to ensure that we maintain privacy, a principle rule in writing this paper has been to exclude identifiable characteristics of any individual, in line with the ASA Ethical Guidelines [64] for good research practice. Our stories are limited by our inherent biases, as two middle-class Caucasian females there is a potential to over-represent middle-class Caucasians in our sample. Using multiple sources and informants to produce bricolage narratives based on contemporary data helps to provide insights into why people in high carbon footprint cohorts go about everyday life in particular ways.

3. Results

The following results section provides the numbers, followed by the narratives. First, we detail carbon footprint distribution by household type, before going into depth in single occupant households followed by dual occupant households. This is an invitation for readers to explore the numbers with curiosity and wonder about what sets the scene for low carbon households.

3.1. Distribution by household type

One-person households make up for 40% of the Danish sample and 42% of the Danish carbon footprint, which is by far the largest share among the different household sizes (Fig. 2). Per capita carbon footprint of this cohort amounts to 9.5 tCO_2eq/cap on average. Two-person households have the highest average carbon footprint per capita at 9.6 tCO_2eq/cap. This type of household has also the highest per capita net income levels at 29.1 thousand EUR annually, which is higher than the average of one-person households at 28.9 thousand EUR (Table 1). Two-person households comprise about 33% of the sample and nearly 35% of the Danish carbon footprint. Together, one- and two-person households link to 77% of the Danish carbon footprint and 73% of the sample, making these highly relevant for climate and social policy.

There are vast income differences among the one-person households; particularly, 34% have annual net income below 20 thousand EURper person, 31% between 20–30 thousand EUR, 16% between 30–40 thousand EUR and 18% above 40 thousand EUR (Table 1). Higher income levels tend to be associated with higher carbon footprints, with income directly determining capacity to consume [32,65,66]. Furthermore, 45% of one-person households have a pension or retirement benefit as a main source of income, compared to 36% and 30% among the two-person households and the total sample. The share of those living from unemployment or other benefits is also the highest among one-person households at 10%, compared to 6% and 8% for the two-person households and the total sample. One-person households are less likely to receive salaries or wages as a main source of income (42%) compared to the total sample (59%). The share of households with

[1] More of Haraway's SF iterations include: science fiction, string figures, speculative feminism, science fact, so far…, SF is about "…giving and receiving patterns, dropping threads and failing but sometimes finding something that works, something consequential and maybe even beautiful, that wasn't there before, of relaying connections that matter of telling stories in hand upon hand, digit upon digit, attachment site upon attachment site, to craft conditions for finite flourishing on terra, on earth." [58] (p.10). We use speculative fabulation to think through our results, 'stay with the trouble' and give space to the narratives that create our understanding of numbers, our world and frame future possibilities.

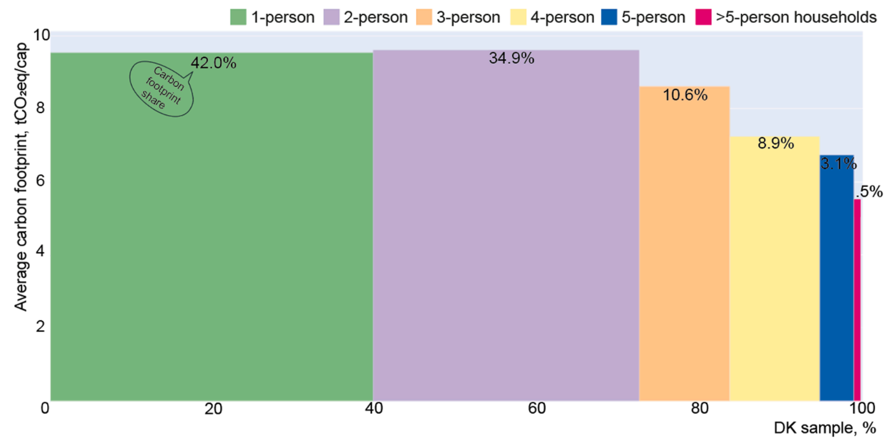

Fig. 2. Danish carbon footprint by household size. The y-axis depicts the average per capita carbon footprint and the x-axis - the share of the DK sample by household size. The area of each rectangular and the labels in % depict the share of the total Danish carbon footprint of that household size (summing to 100%), ranging from one to six and more household members. Figure numbers included in the supplementary materials.

disabled members is the highest among one-person households at 9% compared to 6% in the total sample. Disabled people may have higher energy needs related to mobility, heating and various appliances [50]. One-person households are also more likely to live in energy poverty (20%) compared to the average household in Denmark (14%). Clearly, signs of high carbon contribution coexist with signs of energy vulnerability among single occupant households.

The types of households are also quite diverse in terms of socio-demographic characteristics and location by population density (Table 1). For example, one-person households are predominantly female (54%). The share of people aged over 65 is also higher (36%) relative to the total sample (27%). The share of widowed and divorced is the highest among the one-person households at 48%, compared to only 13% among two-person households. Two-person households tend to consist of both females and males, with relatively low shares of same-sex living: particularly two females make up for 5% of all two-person households and two males - only 3%. The vast majority of two-person households are married couples or couples in registered partnership (67%), while only 5% of the people living on their own are partnered. About 8% of the two-person households consist of one adult living with a dependent child. One-person households tend to be more urban (45%) compared to the two-person and total sample. As much as 65% of the two-person household live in sparsely populated or suburban areas, which are likely to be more car-dependent. This diversity within single and dual resident households can lead to significant diversity on carbon footprints within both household types.

3.2. *Carbon footprints of single occupant households*

Fig. 3 and Table 2 confirm the importance of income as an important determinant of per capita carbon footprints among one-person households. Those earning less than 20 thousand EUR per person have significantly lower carbon footprints at 6.4 tCO_2eq/cap on average. The carbon contribution increases with income, reaching an average of 14.7 tCO_2eq/cap among those earning over 40 thousand EUR per person. Doubling the net income brings about 52% increase in the carbon footprint among single occupant households, holding other socio-economic characteristics fixed (Table 2). Furthermore, those living on income from self-employment and property have 32% higher carbon footprints, compared to those living on wages, retirement,

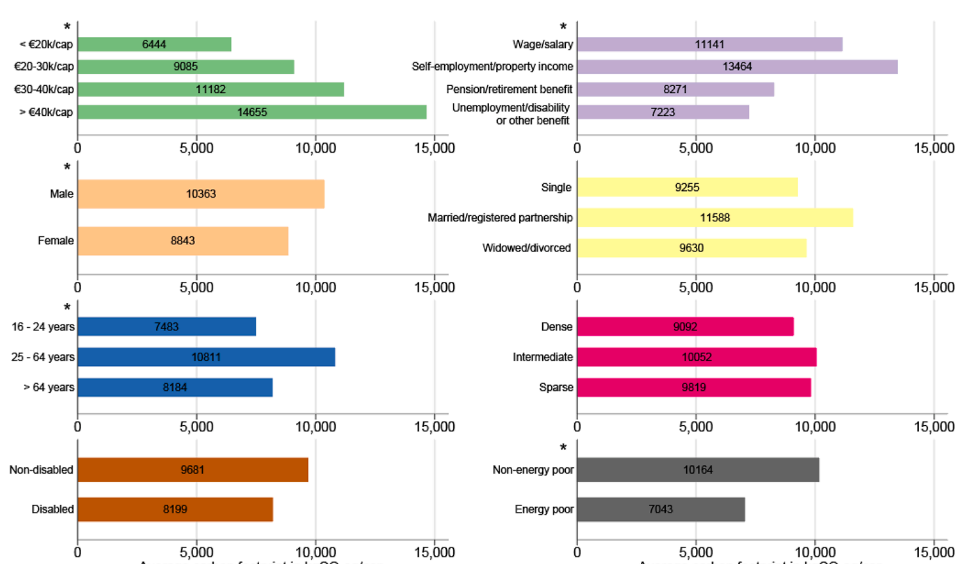

Fig. 3. Danish carbon footprint of single occupant households by various socio-economic characteristics. The asterisks denote cases where the confidence intervals of the means do not overlap suggesting a significant difference between the levels of the variable; see SI Fig. 1 for error bars. None of the one-person is living with children, so we exclude this variable from the variable selection. For multivariate analysis, see Table 2.

Table 2
Multivariate regression analysis for single and dual occupant households. The dependent variable is per capita carbon footprint measured in kgCO_2eq/cap in logarithmic form. As the dependent variable is in logarithmic form, the exponent of the regression coefficients should be interpreted for the variables in linear form (all variables except for income). Coefficients and robust standard errors included in parenthesis. We excluded the intercepts from the table. Significance levels: *<0.1, **<0.05, ***<0.01.

Variable name	Variable definition and levels	Single occupant households		Dual occupant households	
Average net income	Annual net income in € per capita in logarithmic form	0.52***	(0.05)	0.48***	(0.08)
Main source of income Base level: wage/salary	Self-employment/property income	0.28**	(0.11)	0.01	(0.10)
	Pension/retirement benefit	0.11	(0.11)	−0.10	(0.09)
	Unemployment/disability or other benefit	−0.10	(0.08)	0.00	(0.12)
Sex	Female	−0.03	(0.04)	–	–
2-p base level: Two men	A man and a woman	–	–	0.02	(0.11)
	Two women	–	–	0.04	(0.14)
Marital status	Married/in registered partnership	0.09	(0.09)	–	–
1-p base level: Single	Widowed/divorced	0.08*	(0.05)	–	–
2-p base level: Two singles	Two married/in registered partnership	–	–	0.11*	(0.06)
	Two widowed/divorce	–	–	−0.01	(0.11)
	Other combinations	–	–	−0.05	(0.07)
Age	25–64 years	−0.01	(0.08)	–	–
1-p base level: 16–24 years	64 + years	−0.31**	(0.13)	–	–
2-p base level: At least one 16–24 years	Two 25–64 years	–	–	−0.06	(0.12)
	One 25–64 years and one 64 + years	–	–	0.01	(0.07)
	Two 64 + years	–	–	−0.04	(0.10)
Population density	Intermediate	0.03	(0.05)	0.12**	(0.05)
Base level: Dense	Sparse	0.03	(0.05)	0.03	(0.04)
Disabled member	Disabled (dummy variable)	−0.26**	(0.12)	−0.21**	(0.09)
Energy poverty	Energy poor (dummy variable)	0.04	(0.06)	0.12*	(0.06)
Living with children	Household with children (dummy variable)	–	–	0.02	(0.11)
Number of observations		**779**		**951**	
Adjusted R^2		**0.27**		**0.27**	

unemployment or other benefits at fixed income levels (taking the exponent of the coefficient in Table 2).

Women living on their own tend to earn less compared to men and, thus, have lower carbon footprints at 8.8 tCO_2eq/cap on average compared to 10.4 tCO_2eq/cap for men. However, sex and marital status differences are insignificant when controlling for income and other socio-demographics (Table 2). Middle-aged persons have the highest carbon footprint on average at 10.8 tCO_2eq/cap. 25–64 years is the key working age in Denmark and increases in carbon footprints can be attributed to higher income. Controlling for income and other socio-demographic differences, the carbon footprint difference between single occupants younger than 24 years and between 24 and 64 turns insignificant. However, single occupants above 64 years of age still have 27% lower carbon footprint compared to their younger counterparts (taking the exponent of the coefficient in Table 2). The confidence intervals are largely overlapping in terms of carbon footprint differences by population density.

More than 9% of the single occupant households report economic inactivity due to physical or other disability (Table 1), a much higher share compared to the 3% of the dual occupant households. Disabled and energy poor single occupants have lower carbon footprints (Fig. 3): people living with disability have 23% lower carbon footprints even after controlling for differences in income and other socio-demographics, compared to their non-disabled counterparts (taking the exponent of the coefficient in Table 2). This is potentially due to lower access or lower opportunities to consume.

We further investigate the significant variables in our analysis, exploring the total carbon footprint contribution of thirteen cohorts of Danish single occupants, while controlling for differences in income levels, sex, age and disability. Fig. 4 orders the cohorts by the size of the average carbon footprint per capita, highlighting the carbon share of each socio-demographic cohort across single occupant households, summing up to 100%. We aggregate the smallest clusterswith fewer than 30 households.

In our sample males earning over 40 thousand EUR aged below 64 were the highest per capita emitters in the single occupant household, contributing 17% of total carbon among single occupant households or 7% of the Danish total household carbon footprint. All cohorts with annual earnings over 40 thousand EUR contribute to 28% of the carbon footprint of single occupant households, even though they make up only 18% of the sample (Fig. 4). Income is clearly an important driver of carbon footprints with the highest and lowest emitters being associated with the highest and lowest incomes, respectively. Males emit more than females in all income categories apart from 30–40 thousand EUR, where women have a 3% higher per capita emission average. Furthermore, the lowest emitting households are female, with a slightly lower average among women aged between 16 and 64 living on their own. The males and high earners tend to have some of the highest relative contribution from transport and some of the lowest contribution from food and housing (Fig. 5).

People over 64 years contribute to a total of 31% of the carbon footprint and 35% of the sample of single occupant households. The most numerous cohort is women with an income below 20 thousand EUR, who make up 7% of the carbon footprint but 10.6% of the single occupant sample. The majority of these women (67%) live in intermediate or sparsely populated areas. For comparison, low-income males over 64 (<20 thousand EUR) make up 3.7% of the carbon footprint and have higher average carbon footprint. The same low-income male cohort have higher average carbon footprints even than women over 64 with higher income levels (20–30 thousand EUR). The income cohort between 20-30 thousand per person (bigger orange rectangle on Fig. 4) represents primarily widowed or divorced women over 64 (58%). Males over 64 in the lowest income category have much higher transport share (39%), and lower housing and food relative shares compared to other men and women within the same income category. Women over 64 tend to have higher carbon footprint shares associated with food and housing compared to their younger counterparts, who have higher carbon contribution associated with transport, clothing and services (Fig. 5).

The disabled cohort on Fig. 5 suggests some of the lowest transport carbon share at 19% among all cohorts, much lower compared to the non-disabled counterparts at similar income and age (29–41%). The disabled cohort reports higher carbon shares associated with food,

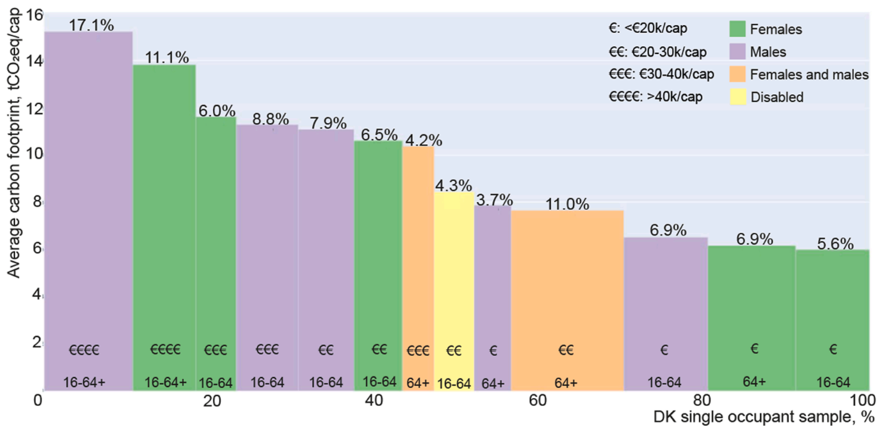

Fig. 4. Carbon footprint of single occupant households by social cohort. The y-axis highlights the average carbon footprints per capita; yet, the differences among the cohorts may not be statistically significant. The x-axis represents the share of the DK single occupant household sample. The area of each rectangular and the labels in % depict the cohort share of the total Danish single occupants carbon footprint (summing to 100%). All cohorts contain at least 30 households. Figure numbers included in the supplementary materials.

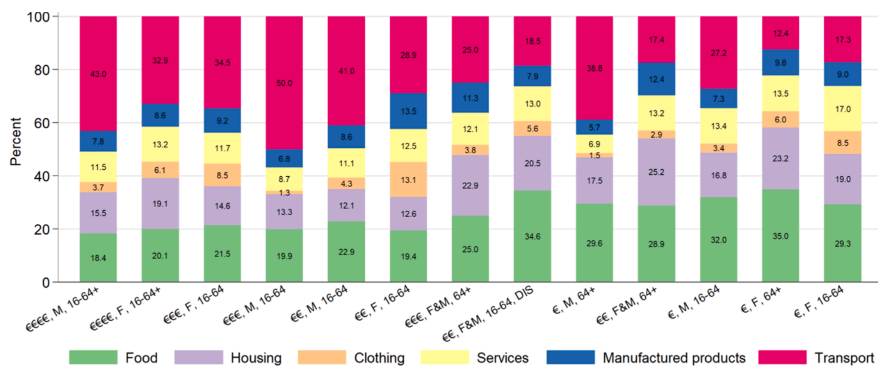

Fig. 5. Average carbon footprint distribution by consumption category and social cohort among single occupant cohorts. We show the carbon footprint share of each category in percentages. The cohorts are ordered from the highest average carbon footprint (on the left) to the lowest (on the right).

housing and other consumption. While there are other disabled people in other income and age cohorts, the cohort sizes were below 30 households, so we could not disaggregate further by disability.

In general, for single occupant households, high carbon footprint cohorts include wealthy males (in terms of carbon footprints per capita) and older women (in terms of the total carbon footprints per cohort). Low carbon footprint cohorts include disabled people and lower income women. Increases in carbon footprints can be attributed to higher income. Sex is also significant: males emit more than females in all income categories apart from 30-40 thousand EUR.

3.3. *Carbon footprints of dual occupant households*

According to Fig. 6, the average carbon footprint of the lowest income households (with net incomes below 20 thousand EUR) is 7.0 tCO_2eq/cap, only half of the 13.9 tCO_2eq/cap of the highest income households (with net incomes above 40 thousand EUR). The average carbon footprints are significantly different at each income level, confirming income as a key factor for carbon footprints also among dual occupant households. Doubling of net income increases the carbon footprint of dual occupant households by 48% (Table 2). Similar to single occupant households, two-person households, whose main income comes from a pension, unemployment or other benefits have much

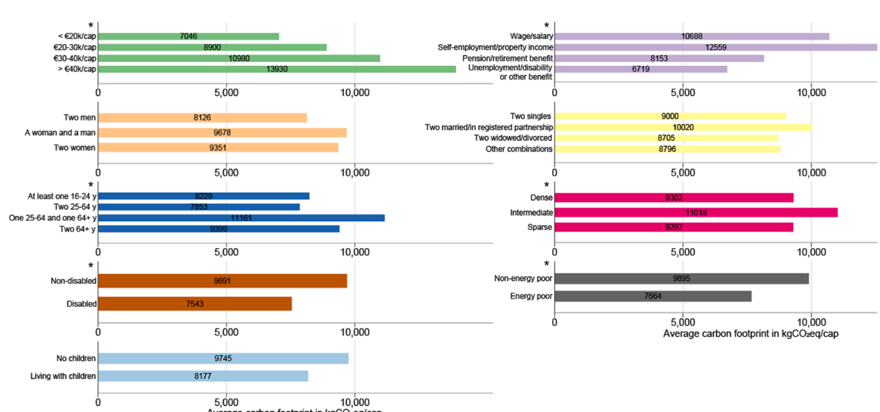

Fig. 6. Danish carbon footprint of dual occupant households by various socio-economic characteristics. The asterisks denote cases where the confidence intervals of various levels of a variable do not overlap suggesting a significant difference between the levels of the variable; see SI Fig. 2 for error bars. For multivariate analysis, see Table 2.

lower average carbon footprints and incomes (Fig. 6), although the regression analysis does not confirm this effect as significant.

The carbon differences by sex are less substantial. Mixed sex dual residents show the highest carbon footprints at 9.7 tCO_2eq/cap and incomes on average. Single sex male dual residents (including couples, housemates, and fathers and sons) have the lowest average carbon footprints at 8.1 tCO_2eq/cap (Fig. 6). Living with children is associated with lower per capita carbon footprint on average, at 8.1 tCO_2eq/cap compared to 9.7 tCO_2eq/cap for dual occupant households without children. However, the effect of having children is insignificant in our regression analysis (Table 2). Married couples or couples in registered partnership have 12% higher carbon footprints compared to other household types (taking the exponent of the coefficient in Table 2).

In terms of age, the highest average carbon footprint is noted for the cohort with one person between 25 and 64 and another over 64 years at 11.2 tCO_2eq/cap, which make up for 48% of the dual occupant household sample. All other ages have substantially lower carbon footprints on average (Fig. 6); however, controlling for income and socio-demographics we cannot confirm a significant age effect (Table 2).

Households living in intermediate population density have 13% higher carbon footprints on average compared to those living in densely or sparsely populated areas (Table 2), in line with other European countries [10,14]. Dual households with a disabled household member have 19% lower per capita carbon footprint (taking the exponent of the coefficient in Table 2). While the carbon differences associated with disability appear substantial, we could not explore them in our cohort positioning analysis as the cohorts with disabled people had less than 30 households at any income level. Furthermore, while energy poor households appear to have lower carbon footprints (Fig. 6), holding income and other socio-demographics fixed, we find a positive and partially significant effect of energy poverty on carbon footprints.

Finally, Fig. 7 visualises the carbon footprint of eleven cohorts of two-person households controlling for differences in income and population density, ordering cohorts by the size of the average carbon footprint per capita. The percentages on the figure reflect the cohort's carbon share of the total carbon footprint of dual occupant households in Denmark.

Households earning over 40 thousand EUR per person together make up for 28% of the carbon footprint of all two-person households, equivalent to 10% of the Danish total household carbon footprint (Fig. 7). Within that income level, the average carbon footprint is the highest among couples, where both persons are between 25 and 64 years of age living in intermediate or sparsely populated regions. Among the highest income earners, the average carbon footprint of households living in intermediate or sparsely populated regions is about 14.5 tCO_2eq/cap. About 34% of the two-person household sample consist of households earning less than 20 thousand EUR per person, contributing to 24% of the carbon footprint of dual occupant households. Their average carbon footprint amounts to 7 tCO_2eq/cap, with the majority of the cohort made up of households with two persons between 25 and 64 years old.

Population density has clear significance for the carbon distribution of dual occupant households. Households living in suburban or intermediately populated areas have higher average per capita carbon footprint at all income levels compared to densely and sparsely populated areas (Fig. 7). Households living in dense areas contribute to 34% of the carbon footprint of two-person households. Furthermore, households living in dense areas tend to have lower transport and housing carbon share compared to other households at the same income level; at the same time, urban households have higher carbon shares of food and services (Fig. 8).

In general, for dual occupant households, high carbon footprint cohorts include married or registered high-income couples in suburban areas. Low carbon cohorts tend to include unpartnered dual occupant household and single adults living with a child, economically inactive disabled people and those living in non-suburban areas. Income is again significant with high incomes increasing carbon footprints.

3.4. Three high impact stories

Departing from high impact cohorts in the single and dual occupant households, the following fabulations speculate the everyday lives of three households with high environmental impact, be they high per capita emitters, or big cohorts. We focus on meanings, emotions and everyday negotiations that lead to high carbon practices. We hope that these narratives are conductive to empathetic and effective policy.

3.4.1. *Single man under 64, big apartment in the city, travels for pleasure, high discretionary income*

Peter is in his early 40 s and lives in a 120 m^2 apartment in Copenhagen's eastern inner suburbs. He likes his job and has a good salary, although he would modestly say that money doesn't matter to him. His son from a previous relationship lives with him every other weekend, so he likes to keep a room to make sure his son feels welcome. When his next-door-neighbours moved out a few years ago he bought their apartment and renovated it together with his existing apartment to give him and his son more space. He re-did the kitchen into one big family room so he could cook and be in the same room while his son does homework and kept two separate bathrooms. Peter makes sure that his son has all of the same toys and books as at his mum's place to avoid too much coordination and potential confusion. He likes to train for triathlons and keeps in shape by competing in two or three international triathlons every year in different parts of the world, most recently in Noosa, Australia. He is active on the dating scene and has a current girlfriend in Tel Aviv so he also likes to spend weekends with her there when his son is not at home, it's a good way to get some sun and a break from Copenhagen. He is interested in good food and wine and likes to prepare dinner parties for friends, and he also likes to eat out. Recently

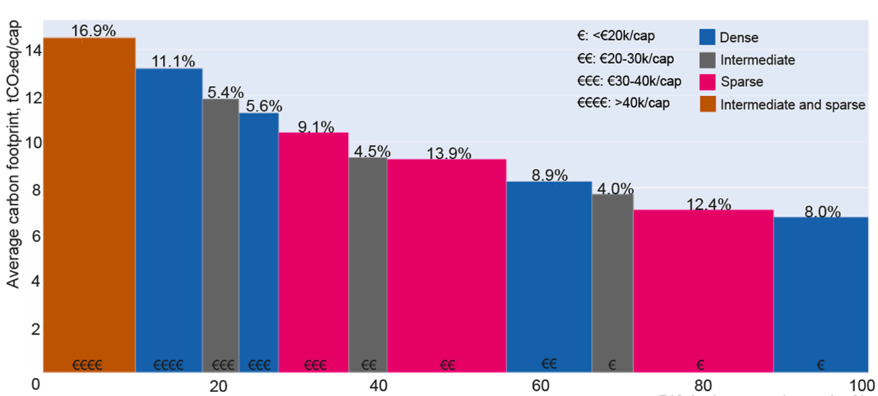

Fig. 7. Carbon footprint of dual occupant households by income and population density. The y-axis highlights the average carbon footprints per capita; yet, the differences among the cohorts may not be statistically significant. The x-axis represents the share of the DK single occupant household sample by household size. The area of each rectangular and the labels in % depict the share of the total Danish dual occupants carbon footprint of that cohort (summing to 100%). All cohorts contain at least 30 households. Figure numbers included in the supplementary materials.

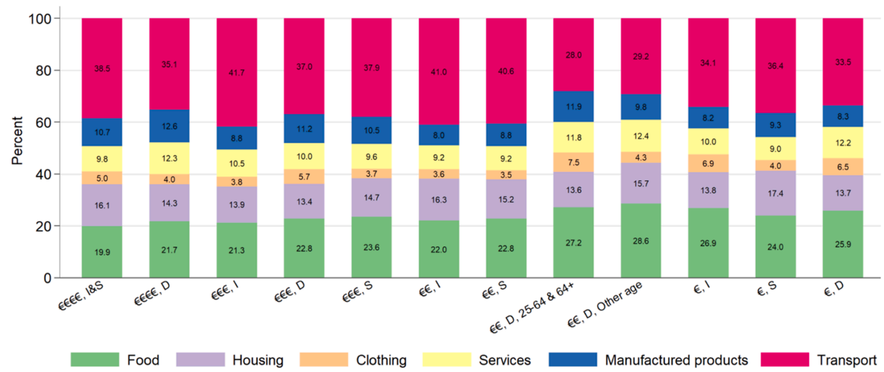

Fig. 8. Average carbon footprint distribution by consumption category and social cohort among dual occupant cohorts. We show the carbon footprint share of each category in percentages. The cohorts are ordered from the highest average carbon footprint (on the left) to the lowest (on the right).

he has been reducing his meat consumption and eating more locally grown food, and his favourite pub now does vegan pølser on Thursdays. Peter has a Tesla model 3, but he cycles to work at least four days per week and only uses his car for weekend trips with his son, and occasional grocery shopping. Peter's work bike is a steel frame fixie, and he also has two triathlon bikes; one for training and a carbon frame competition bike which he keeps in the attic along with his sports equipment. All of Peter's utilities are with green providers, he does not go into details, but he thinks that his energy is renewable.

3.4.2. Single woman, partner dies but she stays in their house

Pernille is in her late 60s and has been single since her partner died twelve years ago. Without actively deciding to, she still lives in their three-bedroom 80 m^2 town house in Lejre where they moved after retiring. Pernille is active and does yoga, paints and regularly visits art galleries. She has five grandchildren and plays an active role in their lives, picking them up from school and looking after them when their parents are busy. The whole family gets together at least once a month, and often at Pernille's house so she likes to keep it well maintained and has a gardener who helps her out once a fortnight. She also likes to have plenty of food for the grandkids and always seems to be doing laundry after they visit - kids! Pernille drives a Peugeot 208 for longer trips or when she has to drive her grandkids, and also has a city bike for shorter trips. She drives into Copenhagen city three times a week for her yoga class, and also flies to Sicily every summer for her annual yoga retreat. When in the city she often goes for coffee with her yoga friends, picks up art supplies and also likes to visit the art galleries, of which she is a member. Pernille also has a membership to Copenhagen Opera and together with her opera buddy, Lene, sees at least three shows a year. Pernille has always liked Southern European food, and while she doesn't eat out as much as she used to, still likes to cook with aubergines, basel, fresh tomatoes, olive oil and other specialty items from the Mediterranean region. She has tried to grow some of these, with limited success so she buys much of what she needs from a wholesale importer. Whenever her family gets together at least once a month she likes to do a bulk order to make sure she gets the freshest ingredients, direct from Italy. Pernille enjoys her life and has never considered other living arrangements, when she becomes too old to look after her house the municipality will send home helpers to look after her.

3.4.3. Empty nest couple in the suburbs, kids leave but they keep the big house in the suburbs and both commute by car to jobs in the city

Pia and Per are in their late 50s and have lived together in their 230 m^2 villa in a leafy suburb 45 min drive west of Copenhagen since their oldest child was born, nearly thirty years ago. Over the years they have renovated and personalised their house and garden and love living there amongst all their happy memories. They also like being able to offer a room if any of their three adult children need a place to crash, and their middle daughter is currently staying in the upstairs bedroom since moving back from Bolivia. Pia and Per have always loved to travel and visited their daughter several times while she was in Bolivia. On their winter break they often fly to Pyhä Fell in Finland with two other families to go skiing and make sure they get some fresh snow. Pia and Per also have a cottage on Anholt island where they spend long periods over summer, doing up the cottage, taking long walks and picking apples from their hobby orchard. They usually drive Pia's Volvo cross country to the cottage as it is four-wheel drive and can navigate the bumpy last miles to their front door. Per prefers to drive his Citröen in the city and would like to give Pia a lift to work, but she's always running late so they end up driving in separately even though they only work a few blocks away from each other. They discussed trying to carpool or joining a car share service but have not gotten around to any action yet. They aren't particularly interested in food and have a food box subscription where ready-made meals are delivered once a week, that way they don't have to do so much cooking or washing-up, although Per does complain about all the packaging that ends up in their bin. They usually get a seasonal box and have also tried the vegetarian and even vegan boxes which they quite liked, but still usually go for the 'default' modern Danish box. Both Pia and Per like to read and subscribe to Dagbladet Politiken and Weekendavisen. They also buy new books online at least once a month and have affectionately christened their son's old room now covered in bookshelves 'the library'. Pia and Per are keen about sustainability and both feel a little guilty about their big house and would like to share or downsize somehow but aren't comfortable to invite a lodger to live with them. Moving to a smaller house closer to the city would cut down their commute time but is too much effort, and they are happy as they are.

4. Discussion

These stories give some qualitative background to the single and dual occupant households that are responsible for 77% of the carbon footprint and make up 73% of the sample in Denmark. Small households also report higher average carbon footprints at 10 tCO_2eq/cap, compared to larger households. Income is one of the strongest predictors among single and dual occupant households, where a doubling of income results in 48–52% increase in carbon footprints. This result supports a clear trend that income is by far the strongest driver of global environmental impacts, dwarfing other factors such as socio-demographics or dwelling structure [11,66].

We also find a common negative and significant effect of disability on carbon footprints presents for both household sizes in Denmark. Households with a disabled member have 23–29% lower carbon footprint compared to other households, holding income and other socio-demographics fixed. This is consistent with prior evidence of lower energy use of disabled people in Europe linked to their inability to afford adequate energy services, which may exacerbate disability as a result [50]. More than 9% of the single occupant households live with disability according to our sample, which is a much higher proportion compared to dual occupant households. This may be related to prior evidence suggesting that health has strong implications for household size; particularly, women with poor health living on their own are more likely to keep their solo living status compared to women with better health [74].

The effects across household sizes diverged in terms of population density. While we do not find a significant effect of population density for single occupant households, dual households in densely and sparsely populated areas have lower carbon footprints than their intermediate-density counterparts. Particularly, those living in two-person households in suburban areas have 13% higher per capita carbon footprints compared to those living in cities. This result is in line with prior evidence on prospering suburbs and countryside cohorts in the UK [75] and potential 'economies of sharing' in rural areas as well [10]. Household consumption also depends on the broader infrastructure that the household has access to, which may be why urban households with access to shared infrastructures (e.g. apartments, public transport) tend to have lower carbon footprints.

Once people live alone, the tendency is to continue living alone [76], and so intervening into these high carbon footprint cohorts before they live alone could entail potential in reducing carbon footprints, especially if in parallel with stimulating low impact residences. In the following section we discuss how we have used storytelling in understanding our results and investigate some potential interventions into the high carbon footprint households.

4.1. Numbers and narratives, science and stories

By including stories from the perspective of high carbon cohorts in our results, we emphasize the value of engaging with the sociocultural elements of energy consumption practices in the present. To reconfigure the high energy everyday lives underlying high carbon footprint cohorts, we need to know about not just *what* people do but have an empathetic feeling for *why* they do it. Stories, we argue, facilitate more compassionate and ultimately more effective interventions for sustainability transitions.

The cohort carbon footprint revealed in our socio-demographic analysis made it easy to identify groups ripe for interventions, while their consumption category breakdowns gave us further insights into where their carbon footprint stems from. Storytelling's relatability is an untapped potential in creating emotional connections to data, and nuanced understandings of meaning in everyday life. By contextualising carbon footprint cohorts with stories, numbers can come alive to encourage compassionate interventions. In this paper our stories have provided less tangible, socially shared ideas to the numbers. We recommend that those faced with designing sustainability transitions follow similar processes of storytelling to understand and empathise with groups they would intervene into the lives of [56]. This will lead away from conceptualising problematic cohorts as high emitting 'villains' and rather illuminate the socially shared ideas about what these groups hold as good or appropriate, as well as their infrastructural and institutional context, and set the scene for socially and environmentally sustainable futures.

4.2. Policy and potential

As single and dual occupant households are responsible for three quarters of the Danish carbon footprint, policy makers should prioritise on small households rather than traditional two-parents-with-children families as the departure point from which to build climate and social policy. Building sustainability should minimise resources required to provide energy services (e.g. heating, cooling, lighting) per person rather than per building – and explicitly consider trends of rising per capita dwelling space in the assessment and management [77]. At the household level, a key policy area may be how to encourage new forms of shared living and downsizing (e.g. co-housing or tiny apartments, shared facilities for guests). Structural barriers (e.g. lack of alternative smaller housing) as well as psychological and social barriers (e.g. concern about loss of ownership, future utilisation of space) need further policy attention [78]. At the city level, the policy focus may extend to enabling cooperative sharing within the community through collective ownership and utilisation of land, infrastructure and resources [77–79].

While sharing is a clear way of addressing small households, income is also a key consideration in sustainability transitions. There is no evidence for absolute decoupling between environmental pressures and income from a consumption perspective, and the observed rates of relative decoupling (the reduction in the environmental intensity of consumption with rising income) cannot bring about the necessary reductions in GHG emissions and resource use in time [11,80]. It follows that wealthy countries such as Denmark should consider direct downscaling of economic production, consumption and resource throughput in order to adequately address the climate crisis, while prioritising the human needs and well-being of its citizens. Denmark provides an interesting case for exploring income's impact on carbon footprint, as compared to other European countries, Denmark has the shallowest correlation between income and carbon footprint [38]. What is it about Danish society that discourages as much consumption as incomes allows? One answer could come from Denmark's progressive taxation, with a nearly 55% tax rate for top income earners. At lower income inequality, transportation-related energy, including fuel for vehicles and flight, decreases, while demand shifts to more residential energy use [81]. At the same time, Denmark reports some of the largest falls of CO_2 emissions from electricity generation [82] and has committed to cover all electricity and heat supply by renewables by 2035 [83]. Since there is so much variation between similar cohorts, there is a need for deeper understanding of the everyday life and energy consumption practices of different cohorts. What seems appropriate or good for high-income single occupant households may differ significantly from low-income single occupant households. These meanings in practice will be vital to the sorts of stories underlying possible futures.

Beyond income, other factors in our analysis appear to have important policy implications as well. Environmental policy needs to better account for the experiences and interests of women, disabled people, older people and those living in energy poverty, who may face more difficulties in the energy transition due to particular energy needs or higher costs (cf. [50]); in our analysis, these groups show lower energy use and carbon footprints, but not necessarily through choice. Cost increases associated with the transition to renewables or efficiency improvements may affect these cohorts disproportionately and further disadvantage them [50].

While small households are a sustainability challenge, sharing should not be achieved at the expense of individual autonomy nor equality. Delaying partnering and fertility decline are particularly evident in highly educated women [84]. However, only to a critical point and then the positive association between gender equity, household formation and stability is stronger in countries with gender-egalitarian norms [85]. Increasing gender equality actually leads, at the societal level, to an increase in couple stability, and thus fewer small households [85]. Sharing households should neither be interpreted as a call for higher fertility: having an extra child in a wealthy country is very high carbon.

Our results show some of the demographic characteristics that shape low and high impact households, however this dataset doesn't allow us to see what kind of living arrangements these people have. Shared communities are also missing from our sample. A further significant characteristic missing from our study is the dwelling space per capita, a key variable in determining carbon footprint, and thus area of interest for future research.

Our study illuminates the social-demographic characteristics of carbon footprint cohorts and their consumption categories, enabling the design of targeted interventions. By using storytelling, we aim to increase empathy and compassion for various carbon footprint cohorts.

Future research should include workshops with policy makers to try out number and observation-based storytelling in the real world. Only then will we be able to qualitatively see how useful storytelling is working toward socially and environmentally sustainable futures.

Data Statement

The data associated with this paper is available from University of Leeds at https://doi.org/10.5518/785.

Declaration of Competing Interest

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

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Appendix A. Supplementary data

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