ENVIRONMENTAL RESEARCH
COMMUNICATIONS

PAPER • OPEN ACCESS

Too much consumption or too high emissions intensities? Explaining the high consumption-based carbon footprints in the Nordic countries

To cite this article: Jukka Heinonen *et al* 2022 *Environ. Res. Commun.* **4** 125007

Environmental Research Communications

PAPER

CrossMark

OPEN ACCESS

RECEIVED
8 September 2022

REVISED
26 November 2022

ACCEPTED FOR PUBLICATION
2 December 2022

PUBLISHED
13 December 2022

Too much consumption or too high emissions intensities? Explaining the high consumption-based carbon footprints in the Nordic countries

Jukka Heinonen[1,*], **Sarah Olson**[1], **Michal Czepkiewicz**[2], **Áróra Árnadóttir**[1] **and Juudit Ottelin**[3]

[1] University of Iceland, Faculty of Civil and Environmental Engineering, Hjardarhagi 2-6, 107 Reykjavik, Iceland
[2] Adam Mickiewicz University, Woj. Wielkopolskie 293, Poznan, Poland
[3] Norwegian University of Science and Technology, Realfagbygget, E4-154, Gløshaugen, Trondheim, Norway
[*] Author to whom any correspondence should be addressed.

E-mail: heinonen@hi.is

Keywords: consumption-based carbon footprint, carbon intensity, mitigation pathway, low-carbon lifestyle

Supplementary material for this article is available online

Abstract

Consumption-based carbon footprints have been widely used to examine how different demand-side solutions can reduce the emissions from personal consumption. This study not only utilized consumption-based carbon footprints to examine how people living in affluent nations like the Nordic countries can live 1.5 degree warming compatible lifestyles, but it also expanded on this analysis by focusing on which level of GHG intensity per monetary unit of expenditure it is possible to remain below a 1.5-degree compatible target level at different levels of consumption expenditure. To analyze the GHG intensity per monetary unit of consumption, first, the consumption-based carbon footprints from around 8,000 survey responses from the Nordic countries were calculated. Then the average carbon intensity per unit of monetary spending was calculated across the income deciles in each country and compared to target levels that align with the 1.5-degree compatible reduction pathways by 2030. Finally, the intensities for selected low-carbon consumption choices (vegan/vegetarian diet, driving an EV, renewable electricity for the home, not owning a car, and no air travel) were calculated and compared to the same baseline targets. Our results showed that all of the average carbon footprints and GHG intensities were above the target levels in all of the countries. However, when comparing respondents having adopted two or more low-carbon consumption choices, there were examples of average intensities that met the target levels. The adoption rates of these low-carbon consumption choices were low though, which illustrates the necessity for high adoption rates of multiple low-carbon consumption choices in order to materialize the potential of demand-side climate change mitigation options. Our findings highlight the importance of examining the GHG intensity of per monetary unit expenditure to inform future policies on demand-side solutions and to improve the climate-literacy of consumers, so they can make more informed decisions on consumption choices.

1. Introduction

Consumption-based carbon footprints have become an important field of research showing how different demand-side solutions can reduce the emissions loads from the perspective of emissions induced by consumption (Ottelin *et al* 2019, Heinonen *et al* 2020). The value of them for GHG mitigation policies is in the allocation of emissions to the end-users instead of where they take place (Afionis *et al* 2017) including the global production and delivery chains. The importance of understanding these globally induced emissions by local activities is further manifested by the increasing role of international trade. As much as one third of all global emissions cross national borders embodied in traded goods (Kanemoto *et al* 2014, Wood *et al* 2018). As a sign of the growing interest around the demand-side solutions, they were recognized in the IPCC WGIII section in AR6 (IPCC 2022) for the first time in the IPCC AR history.

What has been firmly shown in the previous consumption-based carbon footprint literature is that the footprints are tightly connected to the levels of affluence (e.g. Wiedenhofer *et al* 2017, Wiedmann *et al* 2020, Barros & Wilk 2021). On a country-level, the footprints in the developed countries grossly exceed those in the less developed countries (e.g. Clarke *et al* 2017, Hubacek *et al* 2017). Within countries, the more affluent areas tend to show higher footprint levels (Heinonen *et al* 2013, Minx *et al* 2013, Hasegawa *et al* 2015), and within cities the same pattern persists (Heinonen *et al* 2011, Chen *et al* 2018). This pattern seems to be relatively consistent across studies (Ottelin *et al* 2019) when all private consumption is included.

The consumption-based carbon footprints have been extensively utilized for studying the opportunities for emission reductions via lifestyle changes, particularly in the recent years (Jones and Kammen 2014, Vita *et al* 2019, Ivanova *et al* 2020, Koide *et al* 2021a, 2021b). These studies have quantified the reduction potentials associated with numerous lifestyle changes (e.g. reducing meat eating or driving) and other consumer activities (such as choosing green energy and improving home energy efficiency), typically finding that such demand-side actions can be highly effective. Only some of these studies have included the potential rebound effects, however, meaning the effect of spending the money saved from one activity on other consumption causing emissions. The rebounds often reduce the effectiveness of the money-saving demand-side actions (Ottelin 2016, Ottelin *et al* 2017).

While the focus on these demand-side solutions which entail high potential to reduce the emissions induced by private consumption is warranted based on the important role household consumption plays in driving global emissions (Ivanova *et al* 2016), the importance of these actions does not remain constant over time or across space. However, each consumer makes their purchase decisions within their budget limits, meaning that the prices of different goods and services also play an important role in 'the equation of importance' of different demand-side actions, but this issue has thus far received relatively little attention. When a certain action causing high emissions is associated with a low monetary cost, it carries reduction potential with a low risk of significant rebound effect. If a change in demand leads to significant monetary savings, also the rebound potential increases (e.g. Ottelin *et al* 2017). This is due to the importance of the emission intensity of consumption, in other words the emissions per monetary unit of spending on a certain good or activity. With carbon taxes the carbon content of one monetary unit spending on any good or activity causing emissions could be made equal, making carbon footprints almost solely relative to the gross amount of spending. Only as far as there are differences in the carbon intensity of monetary consumption in different consumer goods and services, emission savings can be achieved through changes in the allocation of consumption (spending less on something, but not less overall). Not spending is also an uncertain way to affect the global emissions if it means higher savings rate through the banking system. The so-called second tier rebound after banks lend the saved money for others might be anything below or above 100% (Claudelin *et al* 2020), and tracing them is highly complex.

This study focuses on the understudied topic of the importance of the carbon intensity per monetary unit of consumption. We calculate consumption-based carbon footprints in the Nordic countries for around 8,000 respondents with a carbon footprint calculator survey, calculate the carbon intensities per monetary unit of spending for different income levels, and compare the results against selected baselines, including a global fair per capita share in current emission levels, and a per capita level compatible with 1.5-degree compatible reduction pathways by 2030. The footprints are calculated using a hybrid assessment model combining process information and an input-output model. We show how in all the Nordic countries the intensities per monetary unit of consumption follow a similar path with a strongly decreasing trend towards higher income groups until the very highest where there is an increasing trend again. We also show that, at every level of overall monetary consumption, the intensity is far above the global fair share and the 1.5-degree compatible level. As the second step, we analyze who can reach the target intensity and how. For this we look at selected lifestyle groups to analyze the impacts of engagement into certain behaviors on the carbon intensity of consumption, and if engagement in these behaviors (such as not possessing vehicles, driving an EV, not traveling by air etc.) could lead to sufficiently low overall intensities. Finally, it is discussed how the current trends in income levels and production technologies would affect the findings in the near future, and how the produced information could feed policymaking.

The study covers the Nordic countries, including Denmark, Finland, Iceland, Norway and Sweden, which form an interesting entity with significant similarities across them: they are all highly wealthy in global terms, they have similar economic and societal conditions (often called as the Nordic welfare system), and they have a very low income inequality with high employment rates combined with high tax rates (Jokinen *et al* 2020). They are often seen as leaders in climate change action (Jokinen *et al* 2020), but as highly affluent nations they actually have very high carbon footprints when looked at from a consumption-based perspective (e.g. Clarke *et al* 2017, Hubacek *et al* 2017).

Table 1. Languages versions for each country's survey.

Sweden	Swedish, Finnish, English
Finland	Finnish, Swedish, English
Norway	Norwegian, English
Denmark	Danish, English
Iceland	Icelandic, Polish, English

Table 2. Number of responses from each country with disqualified or incomplete responses in parentheses.

Sweden	2032 (1739)
Finland	2134 (1409)
Norway	1333 (1084)
Denmark	516 (387)
Iceland	1667 (1623)

2. Data and methods

The data includes 8,000 responses to a carbon footprint calculator produced by the authors for this purpose. The sample is explained in detail in the section 2.1 below, and the footprint calculations are explained in section 2.2.

2.1. The survey

The survey aimed at measuring the consumption-based carbon footprints of the respondents, and giving information about their climate attitudes, engagement in pro-climate behaviors, and their self-reported quality of life. The survey was tailored to each Nordic country in terms of the footprint assessments, questions about income levels, and language versions. All the main languages in every country were included as listed in table 1. The survey was administered by the University of Iceland on the web server of the university at carbonfootprint.hi.is.

2.1.1. Survey distribution

Information about the survey and invitations to participate were distributed through Facebook between the fall of 2021 and the spring of 2022, for approximately 2 months in each country, using the marketing services of an online marketing company. No other limitations were set other than the requirements for residential location in one of the Nordic countries and for being an adult either in charge of or participating in the finances of the household. Respondents were also encouraged to share their footprint calculation results and that way 'recommend' to others to take the survey as well. Some news media also picked up the survey which led to additional participants through their audiences. The aim was not set for representativeness over the whole populations of the covered countries, but for as high of a number of high-quality responses as possible. The sociodemographic and potential self-selection biases are discussed later as well as how they should be recognized in interpreting the findings.

2.1.2. Survey respondents

13,924 respondents took the survey in the autumn of 2021 and spring of 2022, of whom 7,682 answered the whole survey. The responses are split between the countries as presented in table 2 (disqualified incomplete responses in parentheses). Each participant gave their consent to use the responses in this study.

Some people took the survey more than once, which was allowed but monitored through asking them in the beginning of the survey to tick a box if they had taken the survey before. After erasing all the duplicate responses from the same participants and erasing the top and bottom 0.5% of footprints to exclude cases where respondents may have greatly over- or under-reported their consumption, the final samples consisted of 1962 responses in Sweden, 2064 in Finland, 1285 in Norway, 1538 in Iceland, and 509 in Denmark.

The respondents were asked for a copious amount of background information. In this study, the focus was on the income levels and the carbon footprints. Income levels were asked both for the respondents themselves, and for their household overall. Of these, the household income was the main variable of interest in this study as

Table 3. Income brackets and the number of respondents in each income bracket.

	Finland (€/month)			Sweden (SEK/month)			Norway (NOK/month)			Denmark (DDK/month)			Iceland (ISK/month)		
Decile	Personal income	Household income[a]	N[b]	Personal income	Household income[a]	N[b]	Personal income	Household income[a]	N[b]	Personal income	Household income	N[b]	Personal income	Household income[a]	N[b]
1st	Less than 1170 (1000)	Less than 2340 (2000)	444	Less than 11050 (10000)	Less than 22100 (20000)	248	Less than 14500 (14000)	Less than 29000 (28000)	147	Less than 11250 (10750)	Less than 22500 (21500)	92	Less than 207000 (200000)	Less than 413800 (400000)	260
2nd	1171–1420	2341–2840	248	11051–14000	22101–28000	242	14500–17800	29000–35600	82	11250–13800	22500–27600	61	207001–254000	413801–508000	160
3rd	1421–1620	2841–3240	191	14001–16850	28001–33700	139	17801–20550	35601–41100	90	13801–15950	27601–31900	50	254001–294000	508001–588000	120
4th	1621–1830	3241–3660	132	16851–19400	33701–38800	166	20551–23000	41101–46000	128	15951–17850	31901–35700	35	294001–329000	588001–658000	104
5th	1831–2050	3661–4100	207	19401–21850	38801–43700	207	23001–25550	46001–51100	73	17851–19800	35701–39600	13	329001–364900	658001–729800	62
6th	2051–2260	4101–4520	143	21851–24450	43701–48900	183	25551–28200	51101–56400	131	19801–21850	39601–43700	78	364901–402700	729801–805400	229
7th	2261–2530	4521–5060	98	24451–27450	48901–54900	144	28201–31250	56401–62500	106	21851–24250	43701–48500	14	402701–446500	805401–893000	53
8th	2531–2890	5061–5780	114	27451–31200	54901–62400	208	31251–35350	62501–70700	115	24251–27450	48501–54900	57	446501–505400	893001–1010800	203
9th	2891–3520	5781–7040	247	31201–36950	62401–73900	173	35351–42250	70701–84500	167	27451–32800	54901–65600	27	505401–603800	1010801–1207600	85
10th	3521–5280	7041–10560	172	36951–55450	73901–110850	205	42251–63400	84501–126800	159	32801–49200	65601–98400	62	603801–905700	1207601–1811400	179
11th	More than 5280 (6000)	More than 10560 (11000)	68	More than 55450 (60000)	More than 110850 (120000)	47	More than 63400 (70000)	More than 126800 (140000)	87	More than 49200 (53000)	More than 98400 (107500)	20	More than 905700 (1000000)	More than 1811400 (2000000)	83

[a] If ≠ personal income.
[b] Based on household income.

Table 4. GHGs associated with each diet in the calculator.

Vegan/vegetarian	1132 kg GHG/a
Pescatarian	1278 kg GHG/a
Omnivore 50 g meat day^{-1}	1533 kg GHG/a
Omnivore 70 g meat day^{-1}	1679 kg GHG/a
Omnivore 150 g meat day^{-1}	2519 kg GHG/a
Omnivore 300 g meat day^{-1}	3213 kg GHG/a

it defines the purchasing power of the household, within which sharing takes place. The respondents had to choose from income deciles based on their country of residence, with the highest 10th decile split into two, the 11th bracket capturing the most affluent. Table 3 shows the household income brackets and the numbers of respondents in each income bracket. Since the affluence of a household is also dependent on the household size, the collected household income was converted into household income per capita by dividing it by the household size. The resulting household income per capita was then the variable utilized in the intensity calculations.

2.2. Footprint calculations

The carbon footprints were calculated using a consumption-based approach (CBA) (e.g. Baynes and Wiedmann 2012) with an input-output (IO) based hybrid assessment model (Heinonen & Junnila 2011) in which the key components are calculated using process information whereas the smaller impact categories are calculated as a direct input-output approach. Within CBA, the method chosen is the so-called Personal Carbon Footprint in which the emissions are allocated to the one purchasing a good or using a service, regardless of where the purchase or use takes place or where the emissions were generated (Heinonen *et al* 2022).

Following this method, the calculator includes all the private consumption activities over a period of one year as estimated by the respondents, except for purchases of vehicles and homes. It was divided into eight main consumption domains of Food, Housing energy, Private vehicle possession and use, Public transport, Leisure travel, Goods and services, Pets, and Second homes. The calculations in each domain are briefly explained below.

Majority of the emissions were calculated using a process LCA approach and literature sources. IO approach was applied to goods and services, which compose around 10%–20% of the carbon footprint in the study, depending on the country. In the study, the Exiobase IO model (Stadler *et al* 2018) was used to determine emission intensities of purchased goods and services. Exiobase is a multi-region (MR) IO model covering 49 countries/regions, including virtually all European countries, and the rest of the world with lower resolution. A concordance matrix was created following Ottelin *et al* (2020) to match the Exiobase sectors with the purchase data. The uncertainties related to the adopted assumptions are discussed in the Discussion section.

2.2.1. Food

The respondents to the survey were asked about their diet, offering them options from a vegan to an omnivore with low to high meat content of their diet. Each diet was assigned an emission load based on an adult daily food consumption average calorific value of 2,200 calories. The GHG values for each diet were taken from Saarinen *et al* (2019) with the omnivore with low and high meat content options extrapolated based on a typical omnivore. Table 4 lists the GHGs associated with each diet in the calculator.

2.2.2. Housing energy

The respondents gave information about the housing type, decade of construction, heating mode, electricity and size of the home. If secondary heating modes were given (e.g. heat pumps & fireplaces), an 80–20 split was used between the primary and the secondary. The energy consumption per m^2 was drawn from Vimpari (2021), and heat pumps were given an average coefficient of performance (COP) of 3.0. Emission factors were calculated for the average grid electricity and average district heat using the official statistics for fuel quantities and scope 1–3 emission factors from Cherubini *et al* (2009) for each fuel. Table 5 lists the final emission intensities for heat and electricity in every country. Finally, the overall housing energy related emissions were divided by the number of people in the household.

2.2.3. Private vehicle possession and use

The respondents were asked to report the number of vehicles in the possession of their household, and one by one tell the type of each vehicle, the fuel efficiency (liters/100 km), fuel type (including an EV option with an assumed efficiency of 12.5 kWh/100 km) (Cherubini, Bird *et al* 2009), and distance driven in the past 12 months

Table 5. The final emission intensities for heat and electricity in each country.

Country	District heat (gCO_2e/kWh)	Electricity (gCO_2e/kWh)
Finland	229	209
Sweden	79	67
Norway	111	18
Denmark	168	199
Iceland	11	19

Table 6. Distances and emission factors used to calculate reported leisure travel.

	Short	Medium	Long
Ferry	2 × 250 km 0.36 $kgCO_2e/km$	2 × 1140 km 0.36 $kgCO_2e/km$	2 × 6000 km 0.36 $kgCO_2e/km$
Plane	2 × 500 km 0.34 $kgCO_2e/km$	2 × 2000 km 0.28 $kgCO_2e/km$	2 × 8000 km 0.28 $kgCO_2e/km$
Train	2 × 500 km 0.08 $kgCO_2e/km$	2 × 2000 km 0.08 $kgCO_2e/km$	2 × 8000 km 0.08 $kgCO_2e/km$
Bus	2 × 500 km 0.15 $kgCO_2e/km$	2 × 2000 km 0.15 $kgCO_2e/km$	2 × 8000 km 0.15 $kgCO_2e/km$
Car	Kilometers driven reported in vehicles section	Kilometers driven reported in vehicles section	Kilometers driven reported in vehicles section

with the vehicle. This sum was then divided by the size of the household. Fuel types for combustion vehicles included gasoline, bioethanol (sugar cane and other crops), diesel, biodiesel (rapeseed, soy, Sunflower), natural gas and biogas. The emissions factors per liter combusted were calculated from Cherubini *et al* (2009) including the scopes 1–3, and for EVs according to electricity in each country as described in table 5.

An option to report secondary fuel was also included as it is customary that in biofuel compatible vehicles the user can choose between fossil- and bio-based fuels. The use of secondary fuels was asked in 10% intervals from 0–10 to 40–50 and coded as 5%, 15% etc.

2.2.4. Public transport

For public transport, one average intensity of 0.12 kg CO_2e was calculated based on indirect emissions drawn from Chester and Horvath (2009) and direct emissions from VTT Technical Research Centre of Finland 2021. The survey participants were asked to estimate their personal average weekly use of public transport in kilometers.

2.2.5. Leisure travel

The survey respondents were asked to report the number of short (0–1000 km), medium (1000–3000 km) and long-distance (3000 km+) trips they had taken in the previous 12 months using ferry, plane, train, bus or car. Table 6 shows the assumed distances and the emission factors per person which were calculated based on Chester and Horvath (2009) and Aamaas *et al* (2013) assuming typical occupancy.

2.2.6. Goods and services

The respondents were asked to report their personal purchases over the preceding 12 months period in the following categories: Alcohol & Cigarettes, Clothing & Footwear, Interior Design & Housekeeping, Health, Recreation & Culture, Restaurants, Hotels, Electronics, and Other Goods & Services. These categories follow the Classification of Individual Consumption According to Purpose (COICOP) (United Nations 2018). The COICOP categories were matched with the Exiobase IO model (Stadler *et al* 2018) following the concordance matrix provided by Ottelin *et al* (2020). Due to a lack of data for basic price - purchaser price -conversion in 2021, year 2015 of Exiobase was chosen and inflation corrections were used to update the emissions intensities to the year of the survey. in the survey, the respondents were given sliders with the Finnish annual average expenditures set as the default value, taken from Alhola *et al* (2019).

2.2.7. Pets

The numbers of dogs and cats were asked, and the yearly emissions were taken as 630 $kgCO_2e$ for dogs from Yavor *et al* 2020 and as 50% of that , 315 $kgCO_2e$, for cats, based on Herrera-Camacho *et al* (2017). The emission

Table 7. Tax rates for personal incomes in each income bracket and the tax information sources.

Personal income group	Tax rates				
	Finland[a]	Sweden[b]	Norway[c]	Denmark[d]	Iceland[e]
1st decile	0.02	0.08	0.15	0.23	0.04
2nd	0.05	0.15		0.26	0.07
3rd	0.08	0.17	0.22	0.28	0.11
4th	0.10	0.18		0.29	0.13
5th	0.15	0.19	0.25	0.30	0.15
6th	0.16	0.21		0.31	0.17
7th	0.17	0.21		0.32	0.19
8th	0.18	0.22	0.33	0.33	0.21
9th	0.2	0.23		0.34	0.23
10th	0.25	0.25		0.36	0.27
11th	0.30	0.30	0.36	0.37	0.30

[a] https://www.vero.fi/en/individuals/tax-cards-and-tax-returns/income/earned-income/tax-rates-on-pay-pensions-and-benefits/
[b] https://www.skatteverket.se/download/18.339cd9fe17d1714c0773e1e/1640186997996/2022_skattetabell32_22.pdf
[c] https://www.skatteetaten.no/en/person/taxes/
[d] https://skat.dk/data.aspx?oid=2035568&lang=us
[e] https://taxsummaries.pwc.com/iceland/

estimates were then divided according to the number of people in the household. Other pets were not included in the footprint calculations.

2.2.8. Second homes

GHG emissions for second homes were taken from Ottelin *et al* (2015), these being 884 kg CO_2e/year for an average Finnish second home owner. This was then divided by the household size.

2.3. GHG intensity of consumption calculations

The GHG intensity of consumption was calculated as:

personal carbon footprint/expenditure, where

expenditure = (gross household income—tax—saving)/household size.

Since the total expenditures of the respondents were not asked in the survey, they needed to be derived. The disposable incomes were derived from the reported gross incomes and taxation in each country at every personal income level. The disposable income was calculated for every household so that the reported personal income was first connected to taxation on that income level, and secondly the remainder of the household income was assumed as the income of a second adult in those households where the reported household income was higher than personal income. These second adult incomes were then also connected to the corresponding tax levels, and finally the household disposable income was calculated as the sum of the two net incomes. Table 7 shows the utilized tax rates for personal incomes in each income bracket and the tax information sources.

To reach the final intensities of consumption, reported personal savings were deducted, and the remaining household expenditures were divided according to the household sizes. The lower income households, when measured by household income per capita, are considerably larger than the more affluent, on average, and save considerably less, as shown in table 8. Due to an error in the question about savings in the Danish language version of the survey, the percentage savings of each income decile from the respondents in Sweden was used to adjust the annual savings of the respondents from Denmark.

2.4. Analyzes

We analyzed two types of settings:

1. The average consumers in the sample in each Nordic country across the income deciles against selected baselines.
2. Selected potentially low-carbon lifestyles against the same baseline footprints.

Table 8. The average household size and annual savings for each income decile in each country.

Household income	Finland		Sweden		Norway		Denmark		Iceland	
Decile	Family size	Annual saving (€)	Family size	Annual saving (€)	Family size	Annual saving (€)	Family size	Annual saving (€)	Family size	Annual saving (€)
1st	2.96	708	2.76	934	3.26	983	2.72	1169	3.80	921
2nd	2.19	1045	2.44	1086	2.65	1487	2.79	1260	3.70	1243
3rd	2.53	1247	2.42	1337	2.53	1451	3.08	1529	3.13	1547
4th	2.23	1761	2.56	1632	3.05	1398	3.43	1811	3.20	1734
5th	1.46	1901	1.65	2001	2.25	2211	1.46	2214	2.39	1999
6th	2.71	1512	3.01	1997	2.99	1939	2.69	2164	3.24	1776
7th	1.71	2112	1.44	2799	1.75	2626	1.57	2943	1.74	3193
8th	1.82	2067	2.19	2784	1.50	3134	2.68	2903	2.62	2969
9th	1.75	2503	1.56	3985	2.20	3127	1.59	4083	1.74	3656
10th	1.82	3679	1.74	4488	1.76	4094	1.73	4685	1.82	4173
11th	1.51	5987	1.55	5392	1.34	6756	1.45	6308	1.41	7326

Table 9. The average carbon footprints for each domain in each country in kg CO_2e.

	Food	Housing energy	Vehicle use	Public transport	Leisure travel	Goods & services	Pets	Summer houses	Total carbon footprint
Finland	1909	1477	1511	222	683	1249	235	153	7437
Norway	2046	339	1291	325	986	835	162	188	6173
Denmark	1886	1781	1101	312	1203	1080	138	61	7562
Iceland	1965	141	1671	106	1402	1254	99	97	6734
Sweden	1829	626	1171	340	578	564	187	131	5426

The baselines and the selected low-carbon lifestyles are described in the following subsections.

2.4.1. Comparison baseline levels

To determine if the footprints calculated in this study were on track to meet the 1.5 °C degree goal of the Paris Agreement we used the current target and the 2030 target from the recent report from Akenji *et al* 2021. The targets in this report are per capita consumption based targets in line with the Paris Agreement and can be considered as a fair consumption space for all since the targets were created through the equal distribution of the remaining global carbon budget to keep global warming below 1.5 degrees (Akenji *et al* 2021). The mitigation pathways used to determine the targets provide at least a 50% chance of keeping warming below 1.5 degrees and minimize the need for negative emission technologies through widespread use of demand-side measures (e.g., Van Vuuren *et al* 2018). The report uses population projections from the United Nations and the share of emissions that can be attributed to household consumption estimated by Hertwich, Peters (2009). The result is the estimated per capita yearly carbon footprint budget (IGES 2019). The current target for 2022 is approximately 3600 kg CO_2e and the 2030 target is 2500 kg CO_2e (Akenji *et al* 2021), which we will use as our baseline comparisons.

The current target of 3600 kg CO_2e and the 2030 target of 2500 kg CO_2e also align with other targets that have been determined to keep global warming below 1.5 degrees including the current average per capita footprint from Ivanova *et al* 2016 and the IPCC pathway (IPCC 2021). Ivanova *et al* 2016 suggested that roughly 65% of the global emissions relate to the personal consumption component, whereas the rest is capital production and governmental consumption. Dividing the global emission levels suggested for each year in the IPCC mitigation pathways by projected population numbers provides the personal per capita emissions targets for each year. The UNEP (2020) Emissions Gap Report 2020 sets the per capita target by 2030 at 2.1 t CO_2.

2.4.2. Selected low-carbon lifestyles

The selected low-carbon lifestyles are the combinations of three major consumption choices (i.e. demand-side actions) that reduce the carbon intensity of consumption without necessarily affecting the amount of money spent on the same good or service:

1. Driving an electric vehicle (EV).
2. Having a vegan or a vegetarian diet.
3. Purchasing renewable housing electricity for the home.

These are the two other consumption choices studied that reduce the carbon intensity of consumption, but can affect the amount of money spent on other goods or services since they are a reduction in consumption:

1. No air travel.
2. Not owning a car.

The consumption choices were studied one by one in each of the countries and compared to the baselines. Then the different combinations of two or more consumption were examined against the baseline as well.

2.4.3. Results presentation

We first give an overview of the footprints across the Nordic countries and the per capita income deciles in each country, divided into the footprint domains described above. After this, the average intensities across the income deciles are compared against the selected baseline levels, and finally the selected potential low-carbon groups against the same baselines and the averages.

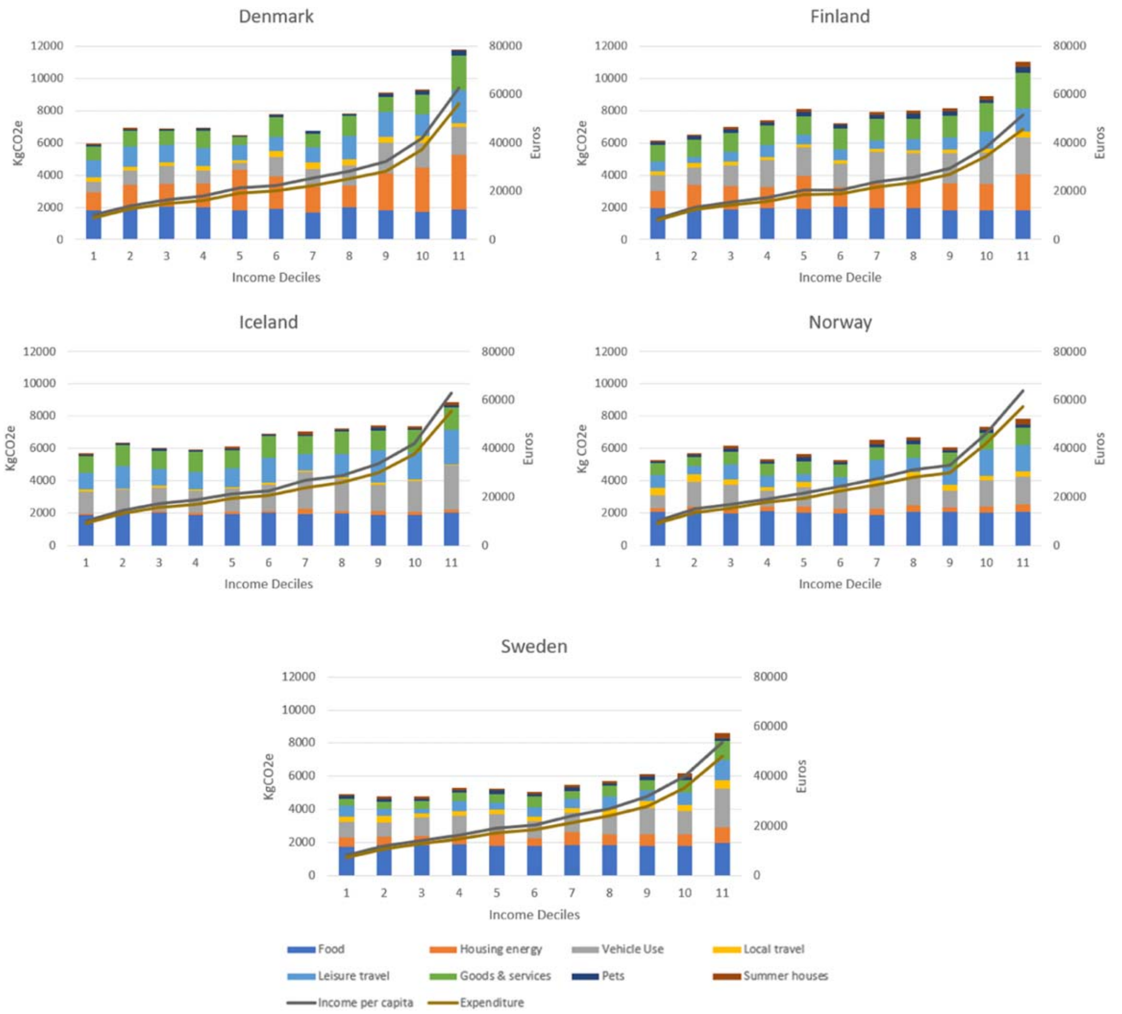

Figure 1. Carbon footprints of the Nordic countries across the eleven per capita income brackets.

3. Results

3.1. Carbon footprints

Figure 1 shows the average carbon footprints calculated for each Nordic country across the eleven income deciles. Footprint totals generally increased as income levels increased. The range of footprints across the income deciles was lowest in income decile two in Sweden (4773 kg CO_2e) and highest in income decile eleven in Denmark (11755 kg CO_2e). The average footprints for each country vary from the lowest average footprint of 5426 kg CO_2e in Sweden and the highest average footprint of 7562 kg CO_2e in Denmark. The higher GHG-intensity of stationary energy production in Finland and Denmark shows in higher emissions in the Housing Energy domain, and in the highest overall footprints. Sweden does not have the lowest stationary energy production GHG intensity, but they have on average very low emissions in the domains of Leisure Travel and Goods & Services, leading to the lowest overall footprints. Among the eight different domains of the carbon footprints, the Food domain, on average had the largest footprint in all of the countries followed by the Vehicle Use domain in all countries except Denmark where the next largest domain was Housing Energy, as shown in table 9.

To be on track to meet the goal of the Paris Agreement, footprints should be at the current target of 3600 kg CO_2e per capita (Akenji *et al* 2021). The footprints would need to decrease between 1173 and 8155 kg CO_2e (25%–69%) to be on track with the current target of 3600 kg CO_2e per capita and to reach the 2030 target of 2500 kg CO_2e per capita the footprints would need to decrease between 2273 and 9255 kg CO_2e (47%–78%).

There were a few cases, where the average carbon footprints of the individual domains of the total footprint reached or exceeded the target levels for the full footprint. In Denmark, the Housing Energy footprints in income deciles 5, 10 and 11 reached above 2500 kg CO_2e and in Iceland, the Vehicle Use footprint in income decile 11 also reached above 2500 kg CO_2e .

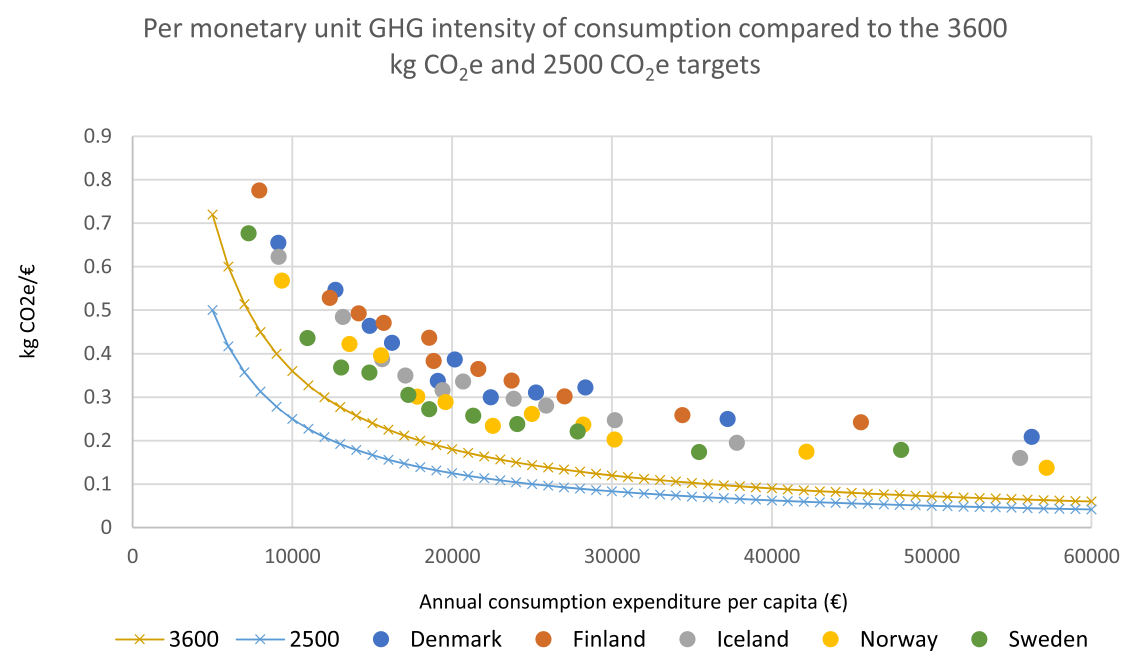

Figure 2. GHG intensity per euro spent of the Nordic countries in comparison to the intensities compatible with 3600 kg CO_2e and the 2500 kg CO_2e targets. Each marker point represents one income decile running from left to right starting from decile 1.

3.2. Intensity

Figure 2 shows the GHG intensity per euro spent for each income decile in each of the Nordic countries in comparison to the current target of 3600 kg CO_2e and the 2030 target of 2500 kg CO_2e, each marker point depicting one income decile running from left to right starting from the decile 1. The intensities ranged from the highest intensity of 0.78 kg CO_2e/€ in income decile one in Finland to the lowest intensity of 0.14 kg CO_2e/€ in income decile eleven in Norway. The intensities generally decreased as the income deciles increased, mainly due to the increasing role of lower-intensity services in the consumption of the more affluent. Denmark and Finland largely had the highest intensities whereas Norway and Sweden generally showed lower intensities. None of the average intensities were low enough to reach either the 2030 target of 2500 kg CO_2e or the current target of 3600 kg CO_2e. The average intensities and number of respondents for each income decile in each country can be seen in the Supplemental section in table B. In figure 2 each point represents the average carbon intensity per monetary unit of consumption for each income decile for each country.

3.3. Consumption choices

When analyzing the consumption choices that have the potential to decrease the carbon intensity of consumption, it was found that one choice was generally not enough to bring the intensities down to the current target of 3600 kg CO_2e or the 2030 target of 2500 kg CO_2, but a combination of two or more choices was able to lower some of the intensities enough to reach them. However, there was one consumption choice where there were examples of the average intensities meeting the current target of 3600 kg CO_2e. This was seen in the consumption choice of driving an EV in income decile 1 in Iceland and in income deciles 3 and 5 in Sweden, which can be seen in Figure 3 below. Table C in the Supplementary section includes all of the combinations of consumption choices and in which income deciles the targets were reached and figure A in the Supplementary section shows the frequency that each consumption choice was chosen for each income deciles in each country.

When combining two consumption choices all of the combinations showed some average intensities that reached the 3600 kg CO_2e target except for some of the combinations with buying renewable electricity for the home, as shown in figures 4–6. The only combination with buying renewable electricity for the home that showed intensities that reached the 2030 target was the combination of driving an EV and buying renewable electricity for the home in Sweden in income deciles 3, 5, and 6 (figure 4). The consumption choice of buying renewable electricity for the home was not included in the consumption choice combinations for Norway and Iceland since the electricity mix for these countries is almost 100% renewable. None of the consumption choice combinations brought any of Finland´s average intensities low enough to reach the targets and only the combination of being a vegan or vegetarian and driving an EV led to low enough intensities in Denmark in income decile 3 (figure 4). All of the consumption choice combinations led to some average intensities low enough to reach the current target of

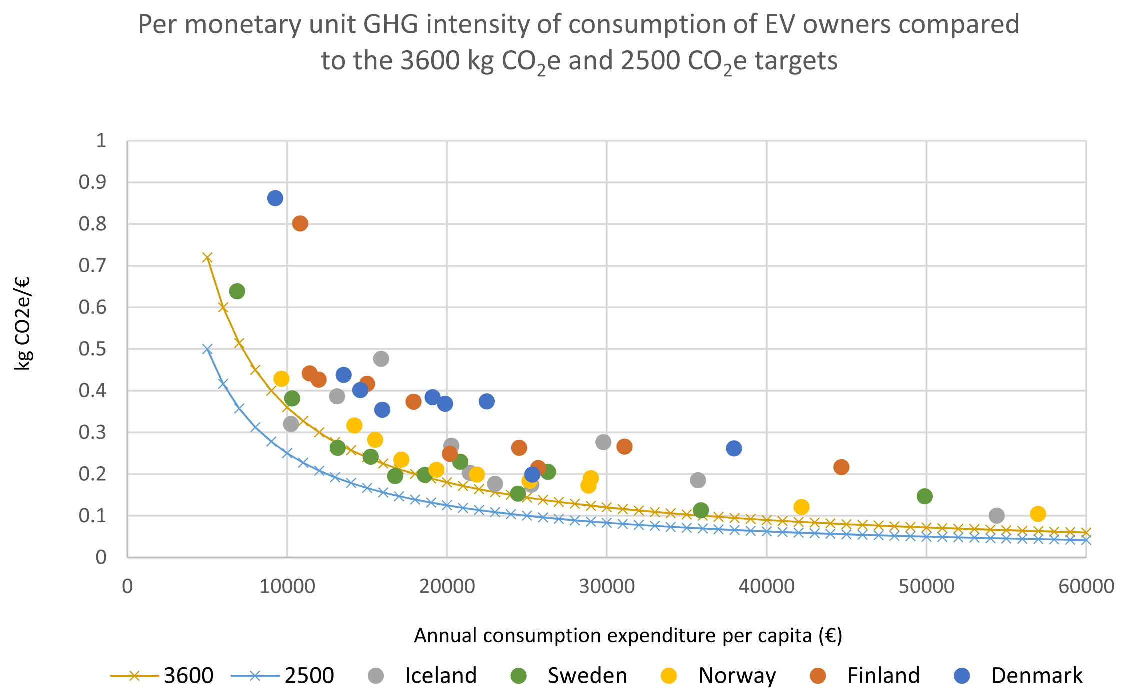

Figure 3. Example of when the consumption choices were analyzed one by one in each country and then compared to the baselines where three average intensities reached the current target for the consumption choice of driving an EV.

3600 kg CO_2e in Iceland and Norway. In Sweden the consumption choice combinations that led to low enough average intensities to reach the target included: being a vegan or vegetarian and driving an EV, being a vegan or vegetarian and not owing a car, being a vegan or vegetarian and no air travel, and driving an EV and buying renewable electricity for the home. Being a vegan or vegetarian and driving an EV was the combination that worked in the most countries (all but Finland) and not owning a car and no air travel showed the most average intensities reaching the current target across the income deciles in Iceland with the target being reached in all income deciles there except for income deciles 2, 5, and 9 (figure 5). Across the countries, the 3600 kg CO_2e target was reached at all of the income deciles with more examples of this in the lower half of the income deciles.

When combining two consumption choices, the 2030 target of 2500 kg CO_2e was reached in two different countries with two different combinations of consumption choices. Being a vegan or vegetarian and driving an EV showed low enough average intensities to reach the 2030 target of 2500 kg CO_2e in Norway in income decile 11 and in Iceland income deciles 1 and 7 (figure 4) and the other combination was being a vegan or vegetarian and no air travel in Norway in income decile 11 (figure 6).

To capture rebound effects, we examined the combination of two consumption choices where one or both of the choices has the potential for the rebound effect (no air travel and not owning a car (figure 5)). These results suggest that rebound effects can be low for some individuals, particularly among people who have made more than one significant sustainable choice. One reason could be that these are people who are highly aware of climate impacts of consumption and avoid GHG intensive consumption in general. However, the focus here was on combinations that led to low intensities, so there may also be a lot of people who are more vulnerable to rebound effects.

When combining three consumption choices, all of the combinations lead to some low enough average intensities to reach the 3600 kg CO_2e target in Norway, Iceland, and Sweden (not including renewable energy combinations in Iceland and Norway), which reached the target in multiple (between thee and seven) income deciles (figures 7–8). Again, no combinations led to low enough intensities in Finland to reach either target and in Denmark only the combinations that included being a vegan or vegetarian (except for being a vegan or vegetarian and buying renewable energy for the home and no air travel) led to average intensities low enough to reach the 3600 kg CO_2e target and this occurred only in income decile 3 and in one instance in income decile 1. Across the countries, there were examples of the 3600 kg CO_2e target being reached at every income decile with more occurrences happening in the lower half of the income deciles. When combining three consumption choices the 2030 target of 2500 kg CO_2e was reached in two different combinations in three countries. Being a vegan or vegetarian and driving an EV and no air travel showed low enough average intensities to reach the 2500 kg CO_2e in Norway in income decile 11, in Iceland in income decile 7, and in Sweden in income decile 1. Then other

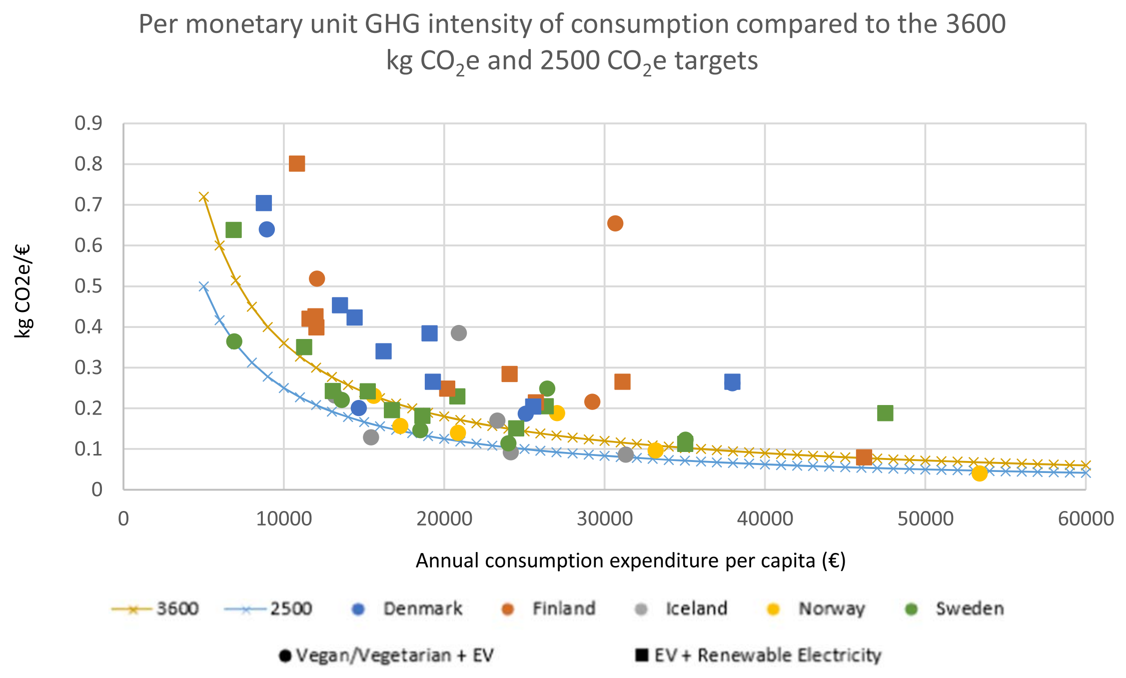

Figure 4. Consumption choice combinations of two choices with a low rebound effect potential that reached the targets.

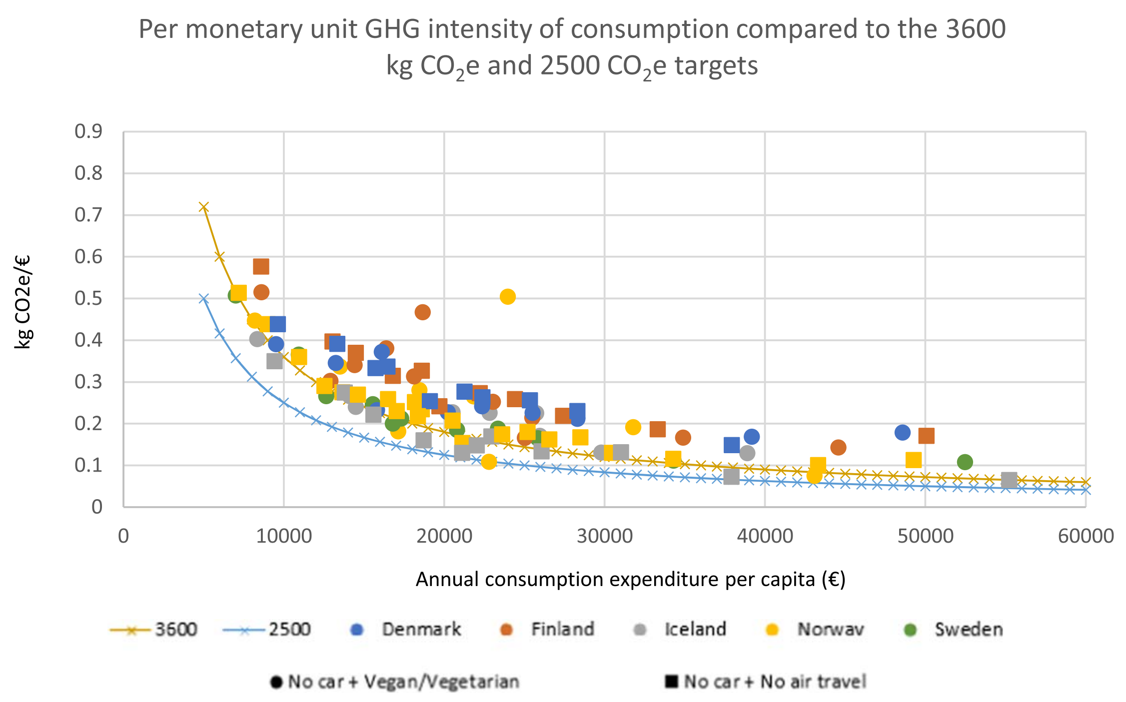

Figure 5. Consumption choice combinations with rebound effect potential that in some countries and income deciles reached the targets.

combination the led to low enough average intensities to reach the 2030 target was being a vegan or vegetarian and no air travel and no car in Norway in income deciles 4 and 6 and in Iceland in deciles 2 and 6.

4. Discussion

The average consumption-based carbon footprints estimated in our study for various income deciles in the Nordic countries range between 4.8 t CO_2e and 11.8 t CO_2e. These footprints would need to decrease between 1.2 and 8.2 t CO_2e (25%–69%) to be on track with the current target of 3.6 t CO_2e per capita and by 2.3 to 9.3 t

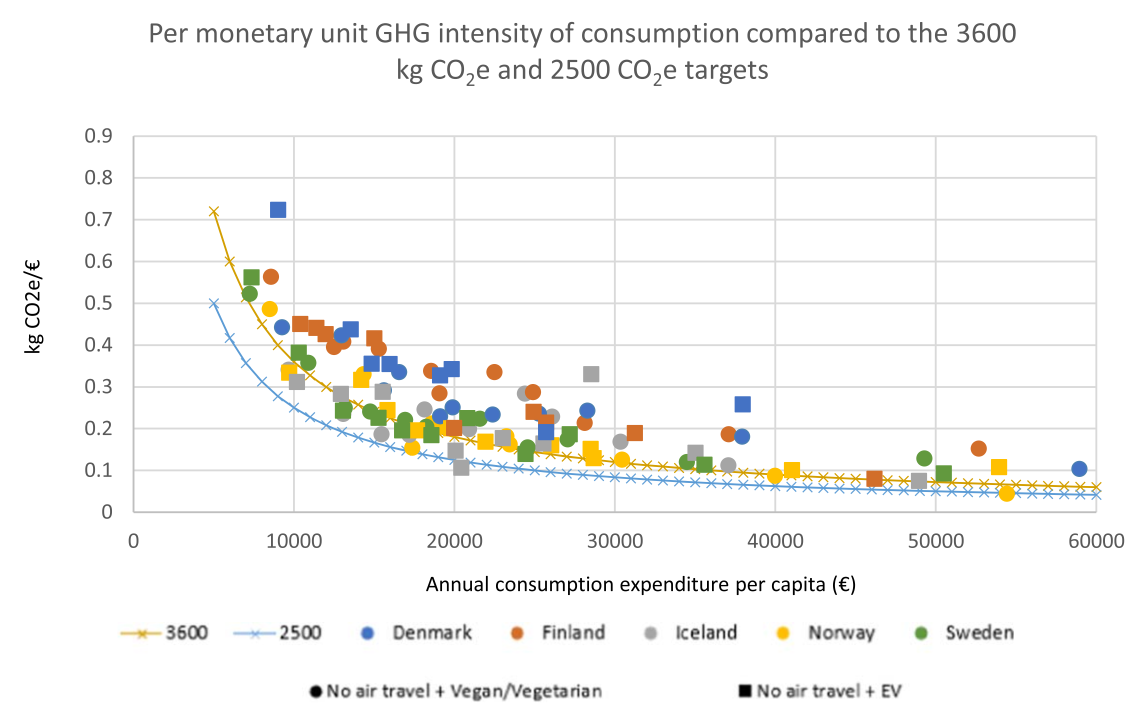

Figure 6. Consumption choice combinations with rebound effect potential that in some countries and income deciles reached the targets.

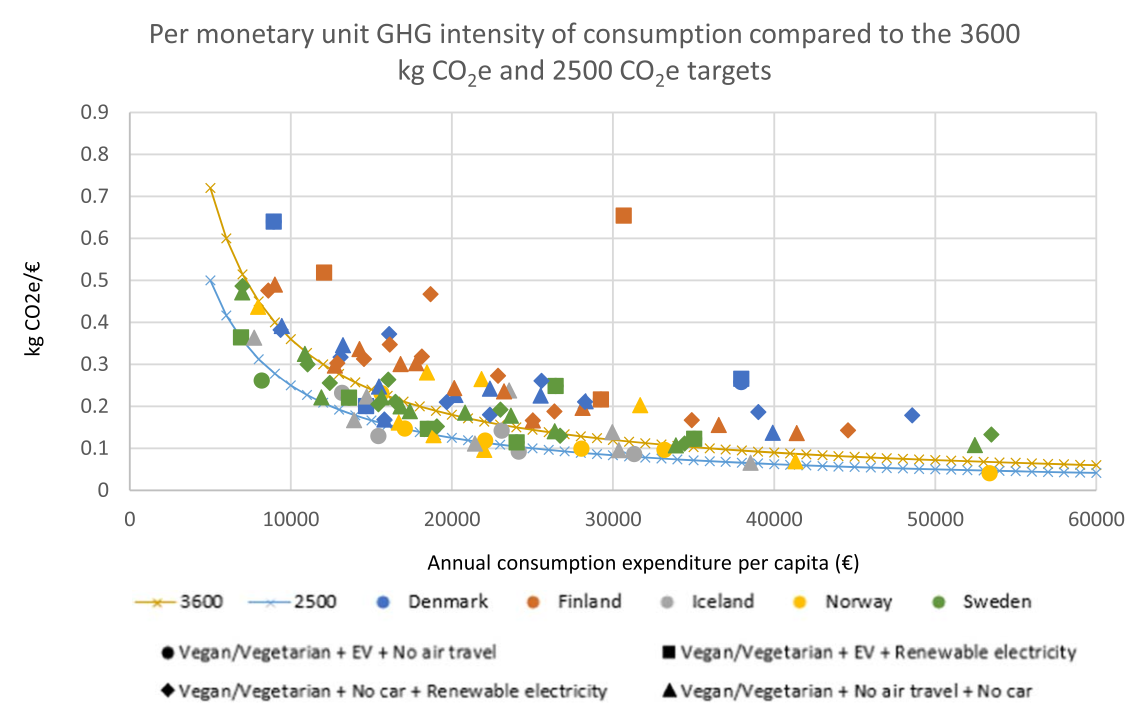

Figure 7. Combinations of three consumption choices that in some countries and income deciles led to low enough intensities to reach the targets.

CO_2e (47%–78%) to reach the 2030 target of 2.5 t CO_2e per person. The scale of reductions highlights the great challenge of bringing emission levels in affluent countries to 1.5 degree-compatible and globally-fair levels.

There was some variation seen in the domains of the footprints among the countries. Iceland and Norway had the lowest Housing Energy footprints due to having almost 100% renewable electricity and low carbon heating methods, whereas Denmark and Finland had higher Housing Energy footprints due to having more fossil fuels in their energy mixes. Being an Island, Iceland has a higher reliance on imported goods than the other countries, and in order to travel internationally, residents rely heavily on air travel, which could explain why

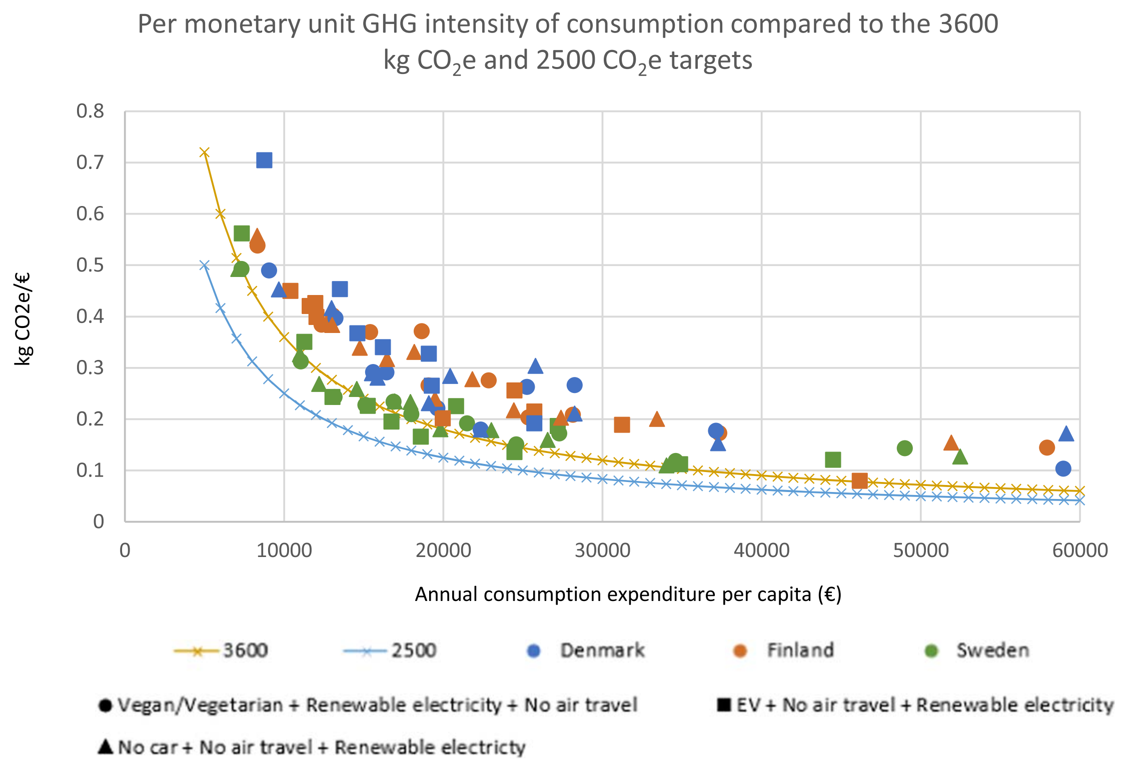

Figure 8. Combinations of three consumption choices that in some countries and income deciles led to low enough intensities to reach the 3600 kg CO_2e target.

Table 10. Number and percentage of respondents in each country who chose the low-carbon consumption choices analyzed.

Country	Total	Vegan and vegetarian		Renewable electricity		No Car		No Air Travel		EV	
		Total	%	Total	%	Total	%	Total	%	Total	%
Sweden	1962	402	20	1185	60	471	24	1713	87	98	5
Norway	1285	70	5	n/a	n/a	243	19	922	72	146	11
Iceland	1538	155	10	n/a	n/a	148	10	843	55	82	5
Finland	2064	270	13	1126	55	563	27	1833	89	38	2
Denmark	509	102	20	228	45	185	36	381	75	29	6

Iceland had the highest average carbon footprint in the Goods and Services domain and the highest Leisure Travel footprint. The respondents from Iceland also showed a higher participation rate in flying than the other countries. Denmark, Finland, Norway, and Sweden all have more public transportation options and infrastructure than Iceland, which may explain why Iceland had the lowest average footprint in the Public Transportation domain and the highest average footprint in the Vehicle Use domain. The number of respondents who chose the low-carbon consumption choices showed some variation across the countries and income deciles. Table 10 shows how many of the respondents chose the low-carbon consumption choices in each country. Across the income deciles, being a vegan or vegetarian and buying renewable electricity for the home did not show any trends of increasing or decreasing engagement over the income deciles. No air travel showed a slight decrease in the upper income deciles in all of the countries and driving an EV showed a slight increase in participants in the higher income deciles in some of the countries. Respondents chose not owning a car slightly more in some countries in the lower income deciles except in Iceland where this choice was shown quite evenly across the income deciles. The percent of respondents who chose each low-carbon consumption choice in each income decile can be seen in the Supplemental section in figure A.

Some of the similar rates of participation in the low-carbon consumption choices across the countries and income deciles may be due to the Nordic countries being welfare states and highly affluent countries. The Nordic countries also have very little energy poverty (Maxim *et al* 2016). Residents of the Nordic countries have comparable purchasing powers with the exception of Norway which has a higher purchasing power than the other countries (Eurostat 2022). The Nordic countries have some of the highest levels of median annual disposable income in Europe (Eurostat 2022) and lowest levels income inequality (Jokinen *et al* 2020), so the cost of air travel may be less of an obstacle to travel long distances for residents of these countries similar to what was found in the study from Czepkiewicz *et al* (2019) of travel habits and emissions of urban dwellers in Reykjavík, Iceland. Similarly, possessing and operating a vehicle, even a low-emission one, is typically not out of reach even for the lower income households, which shows as relatively equal adoption rates across the income deciles (see the supplementary section figure A). Our results highlight the high potential of demand-side climate change mitigation options for reducing carbon emissions, the point increasingly made in recent literature (Creutzig *et al* 2022a, 2022b). High-impact choices to reduce GHG emissions include changes in transportation (e.g., car-free living, driving an EV, avoiding air travel), adopting plant-based or vegetarian diets, improving the energy efficiency of dwellings or reducing their size, and opting for renewable energy supply (Wynes and Nicholas 2017, Ivanova *et al* 2020). Our study illustrates that even in countries with a low carbon intensity of electric energy, such as Iceland and Norway, lifestyle changes are necessary to bring footprints to 1.5 degree-compatible levels.

We also highlight that it takes multiple behavior changes to bring a personal carbon footprint to the target levels. Other research in affluent countries has reached the same conclusion, adding that high adoption rates are necessary to reach the targets at societal scales (Akenji *et al* 2021, Koide *et al* 2021a).

Previous studies suggested that demand-side climate change mitigation can be vulnerable to rebound effects, which occur when consumption choices create monetary savings, which allow for changes in consumption in other areas (Ottelin *et al* 2020). Sufficiency scenarios, with a net reduction in consumption, have a higher mitigation potential and a higher risk of the rebound effect (Ottelin *et al* 2020, Sorrell *et al* 2020). For example, Ottelin *et al* 2020 found a rebound effect in Finland among those who do not own a car in that they spend more on public transportation or holiday travel, compensating for the emission savings of not owning a car. Conversely, a vegetarian diet did not show significant rebound effects on material footprints since it may not significantly reduce overall food costs (Ottelin *et al* 2020). Green consumption options, which reduce emissions without reducing cost, such as driving an EV or buying renewable energy for the home, have less of a risk for the rebound effect, but might have the potential to increase land and water requirements (Vita *et al* 2019).

Here, we found that at the individual level, rebound effects may be avoidable, as might be expected. We found some consumers who have reached a target level by combining two or more low-carbon choices, such as a vegetarian diet and not flying or not owning a car in some Nordic countries. These choices could potentially have high rebound effects, so it may be that the found individuals are avoiding carbon intensive consumption in general, thus avoiding significant rebounds. However, this does not mean that the combination of such actions would always lead to a low enough carbon footprint. On the contrary, considering the sample sizes, reaching a target level seems quite exceptional. Rebound effects are likely to be higher among the general public, as suggested by previous studies, which should be considered in the planning of policy interventions.

Typically, consumption-based carbon footprint studies have shown the sizes of the footprints in a certain location, how much the footprints would need to be cut to reach a climate-sustainable level, or how much they can be cut by adopting certain consumption choices. Besides adding to this tradition, this study took a step forward by showing at which level of GHG intensity per monetary unit of expenditure unit it is possible to remain below a certain footprint target level. We argue that this discussion is important and has been underrepresented in previous literature. Without dramatic changes in how climate sustainability is sought or how wealth and incomes are distributed, there will likely be high consumption levels in the future, particularly in the very affluent Nordic countries. Therefore, it is crucial to look at the carbon-intensity aspect of the current footprints compared to the levels compatible with the 1.5-degree targets suggested in the literature.

Despite their high reduction potential, demand-side changes alone may not be enough to bring carbon footprints down to 1.5 degree-compatible levels, especially when more stringent targets by 2040 and 2050 are considered (1.4 and 0.7 t CO_2e, respectively, according to Akenji *et al* 2021). For example, the target carbon footprint of diet has been estimated at 0.4 tCO_2eq/cap (Girod *et al* 2014, Ivanova *et al* 2020). The lowest footprint of plant-based diets in our assessment, based on a study on the diet climate impacts in the Nordic countries (Saarinen *et al* 2019), is above one ton. It provides a high reduction potential compared to omnivore diets. However, it is still significantly higher than the target mentioned above for diet footprint (0.4 t CO_2e) and higher than the target for the whole lifestyle footprint by 2050 (0.7 t CO_2e). It suggests that, even in the case of vegan or vegetarian diets, further changes in farming and processing techniques and diet composition (e.g., avoiding high-impact plant-based foods) may be necessary. To reach climate targets, technological and lifestyle changes must be widely implemented (Mundaca *et al* 2019, Wiedmann *et al* 2020). It has also been claimed that the energy consumption must be reduced particularly in the more affluent locations to allow for renewable energy transition (Seibert & Rees 2021).

4.1. Policy outlook

Our study highlights the need to support the wide adoption of demand-side climate mitigation options in affluent societies, such as the Nordic countries. There are multiple ways that consumers can reduce their carbon footprints, so policies must reflect and support many options to reduce carbon footprints. In line with e.g. Dubois *et al* 2019, our study highlights that policies that support and reinforce behavior changes that will lead to changes in consumption choices in the areas of transport, diet and renewable housing energy can be effective and are necessary to help realize the potential of these choices to mitigate climate change.

Our study also highlights the need for policies that educate and promote the importance of consumers making consumption changes in multiple domains concurrently (e.g., adopting a vegan diet and avoiding flights). It is particularly important in light of the findings that individuals often use various strategies of moral disengagement, such as using reductions made in one domain (e.g., diet or daily travel) to justify high-impact behavior in another (e.g., flying) (Sörqvist, Langeborg 2019, Árnadóttir *et al* 2021). Our study also emphasizes the importance of prices. Even the current high-emitting consumption options can be brought to whatever intensity per monetary unit of spending level by changes in pricing via e.g. taxation.

Our study's adoption rates of some of the most impactful consumption choices are relatively low (table 10). To bring the average carbon footprints to target levels, the adoption rates must be much higher. This suggests the need for stronger policies supporting society-wide lifestyle changes in key domains. These include, but are not limited to, reducing car dependence (Mattioli *et al* 2020) and improving conditions for walking, cycling, and public transportation, increasing taxes and removing subsidies in aviation (Gössling and Dolnicar 2022), promoting plant-based diets, changing the subsidies and taxes related to meat production, and subsidizing investments in the energy efficiency of buildings. Overall policies should support consumption of goods and services with low carbon intensity, and, vice versa, taxation and other tools available for the decision-makers should be utilized to increase the prices of carbon-intensive goods and services, and to decrease the prices of the low-intensity options. As claimed throughout this paper, the intensity should be better acknowledged to find effective mitigation mechanisms.

It has also been claimed that societal equality plays a significant role in effective climate mitigation (e.g. Green and Healy 2022). According to the claim, integrating carbon-centric policies into societal reforms would lead to more effective decarbonization climate policies alone The Nordic countries are among the most equal globally, and despite the low overall adoption rates in our data (table 10), the engagement shares vary relatively little across the income deciles (Supplementary figure A) which together with the relatively low overall differences from the lowest to the higher income segments might support this claim. However, it should be studied further also in this context if the most effective climate policies would be those that simultaneously support further inequality reductions.

Focusing on carbon intensity instead of absolute emissions can help avoid unwanted rebound effects. Rebound effects are the most severe where monetary savings lead to increased consumption of the most carbon-intensive consumption categories, such as flying or fossil motor fuels. Thus, policies that focus on bringing the carbon intensity of all consumption to a sustainable level are important. Alternatively, the consumption of carbon-intensive products and services (e.g., air travel) can be restricted or disincentivized. It should be understood that if there are not strong enough policies targeting the carbon-intensive consumption categories, targeting other, lower-intensity categories may be harmful to the environment due to rebound effects.

4.2. Limitations and uncertainties

In this study, we focused on the personal consumption component of the carbon footprint, leaving out governmental consumption and capital formation. According to Ivanova *et al* 2016, this component is responsible for around 65% of the overall, meaning that the footprints are significantly higher when all components are included. However, the personal consumption component is the one with which individuals have the most control, so it is relevant to look at it separately. It is also a common practice to focus on (Heinonen *et al* 2020). We also chose the target levels to comply with our footprints' scope. The scope differences are the main reason why average per capita footprints in our sample are lower than those reported in previous studies in the Nordics: 12.2 to 15.2 t CO_2e in Denmark (Hertwich, Peters 2009, Ivanova *et al* 2016), 8.88 to 18 t CO_2e in Finland (Hertwich, Peters 2009, Ala-Mantila *et al* 2016, Ivanova *et al* 2016, Salo and Nissinen 2017, Koide *et al* 2021a), 10.4 t CO_2e in Iceland (Clarke *et al* 2017), 10.3 to 14.9 t CO_2e in Norway and 8.7 to 10.5 t CO_2e for Sweden (Hertwich, Peters 2009, Ivanova *et al* 2016). Other reasons include the changes in carbon intensities and consumption patterns since the other studies were conducted, as well as potentially higher adoption rates of the demand-side actions in our sample than in whole societies.

We used per capita as the functional unit, which is the most widely utilized choice (Heinonen *et al* 2020). This might exaggerate the sharing benefit from within household sharing as all members of the household have equal weight (Ala-Mantila *et al* 2016). Adult equivalents (or consumption units) could theoretically be a better option, giving the weight of 0.5 for second and thereafter adults, and 0.3 for children. This functional unit has been utilized in some CBA studies (Ala-Mantila *et al* 2016, Jaccard *et al* 2021), but not widely (Heinonen *et al* 2020) potentially due to the easiness of interpreting the per capita results. In the future more studies should compare the results when using these two functional units.

In addition, we calculated the footprints allocating to the consumers all the emissions based on their consumption activities and their global GHG consequences (i.e., the personal carbon footprint), not those from consumption in a selected location. Both are widely used approaches in consumption-based carbon foot-printing, but even though they might lead to highly different outcomes, they are often taken as the same (Heinonen *et al* 2022).

The representativeness of the data may be a limitation of the study. The data collection did not aim at representativeness but at large enough samples to detect low-carbon lifestyles. Therefore, we do not claim that the footprints represent the averages in each income level and country, even though they provide a good indication of between-group differences. The Danish sample is also significantly smaller than those of the other countries. Still, the results for Denmark are in line with the other countries. A table comparison of some key socio-economic qualities between our samples and the country averages across the studied countries is provided in the supplementary information section in table A.

There might also be a self-selection bias in our sample towards people engaging in low-carbon consumption, and therefore having higher interest in participating in our survey. However, the engagement rates are still low as shown by table 10, meaning that the majority of the respondents do not participate in them. The low sample sizes shown in table 10 mean that only a few individuals would reach the target levels, especially in particular income deciles. For example, in Iceland, for the consumption choice of being a vegan or vegetarian and driving an EV, the number of respondents who engaged in this combination of consumption choices was only eight. Of the eight, only two had low enough carbon footprints to reach the targets. Our analysis only shows the potential of certain consumption choices to lower carbon footprints to the target level and does not claim that everyone who chooses these consumption choices will result in a carbon footprint at the target level since the total footprint relies on other factors than these consumption choices.

The respondents could also have over or under-reported their spending and even altered their actual consumption habits. However, the relatively large overall sample sizes are expected to overshadow individual misreporting. Furthermore, unlike in traditional household budget surveys, we asked about consumption throughout the year, not only during a short survey period. Thus, smaller sample sizes can provide a reliable picture of the average consumption of a specific group. We also erased the top and bottom 0.5% footprints to avoid inclusion of the most likely cases of over or under-reporting, as was explained in the Data and Methods section.

The survey was conducted during the COVID-19 pandemic, so respondents could have traveled less than they normally would have for commuting and long-distance leisure trips or spent less on leisure services and eating out. The footprints we calculated align with those calculated in previous studies, and therefore the biases are likely not significant in other domains but air travel. Surprisingly many respondents did report air travel regardless of the pandemic. Still, the emissions in that domain are lower than before COVID, as indicated by Czepkiewicz *et al* (2018, 2019) for air travel emissions in Finland and Iceland.

The survey did not include the production of homes, cars, or other major durable goods. Of these, the construction of new homes is a major source of emissions (e.g. Ottelin *et al* 2015), but it is also common to leave it out as it can be considered a part of the capital formation component (e.g. Mach *et al* 2018). Production of new vehicles has also been found to add up to one ton to the footprint of the more affluent (Heinonen *et al* 2020) and, therefore, could cause some downward bias in our assessments. Production of other durable goods left out from the survey has not been suggested as highly significant in previous literature (Heinonen *et al* 2020).

IO models, including the Exiobase model used in this study, have some inherent uncertainties related to sector aggregation and other modelling assumptions. Here, the role of the IO approach was relatively low because a major part of the footprint assessment uses other data sources: the footprints in food, home energy use, car use, long-distance travel, public ground transport, second homes, and pets categories are not based on expenditures but reported use (see Data and Methods for details). However, there is some uncertainty in the values chosen from the literature to calculate these othe domains of the footprints. For example, for heat pumps, a COP of three was chosen from Vimpari 2021, however the COP can vary with the outdoor temperature and model of the heat pump. A COP of three is a typical middle value for heat pumps and this value has been used in other studies on heat pumps such as Gram-Hanssen *et al* (2012) for Denmark. Again, the uncertainty coming from this is relatively low since the heat pump calculation accounts for a small part of the overall footprint, the share of heat pumps in the sample is relatively small, and this is mostly only important in Finland and Denmark due to their energy mixes having more fossil fuels than the other countries.

Our assessment actually includes important improvements compared to traditional carbon footprint assessments. First, it is well-known that air travel emissions are not well captured using consumption expenditure data or similar (Heinonen *et al* 2020) due to the monetary values correlating only weakly with numbers of trips and flown distances. IO model intensities also typically exclude the short-term radiative forcers which cause a highly important share of the overall warming impact (e.g. Lee *et al* 2021). In our assessment, we utilize trip numbers and distances and include the effect of short-term radiative forcers. Second, our car travel estimates are advanced from the perspective that they use the reported fuel types vehicle fuel efficiencies instead of fuel purchases, which leave the fuel type invisible and lead to overestimations when biofuels are used. Third, our public and long-distance ground transport assessments use reported modes and distances instead of monetary purchase data, improving accuracy significantly. Finally, energy payments, particularly heating, are often embedded in rents and housing management fees (Heinonen *et al* 2020), making our home size and building age-based assessment more reliable. All the utilized emissions factors also include indirect production and delivery chain emissions. Still, future studies may further improve the accuracy of carbon footprint assessment by collecting more detailed data on purchases of durable goods, and on the usage of specific products, especially in the food domain, or direct measurement of household energy use.

5. Conclusions

By conducting a survey with personal carbon footprint assessment across the Nordic countries, our study highlights the vast potential of demand-side climate change mitigation options at the household level to bring carbon footprints down to the 1.5 degree-compatible targets suggested in the literature. For this to be effective, however, a simultaneous adoption of multiple lifestyle changes (e.g., a plant-based diet, no car, and no flights) is necessary. Furthermore, to bring average footprints to the target levels, wide adoption of these (combinations of) options is needed. It suggests a need for a stronger emphasis on demand-side mitigation in climate policy. The findings can also improve the climate-literacy of people, giving them an opportunity for better-advised purchase decisions, particularly the combinations of changes that lead to footprints below the current target level even at high affluence levels. While reducing carbon footprints and carbon intensity to the current (2022) and by 2030 targets with demand-side options alone may be possible, further reductions will still require changes in production technologies.

Acknowledgments

The authors thank the Icelandic Centre for Research RANNIS for funding this study (grant number 207195-052).

Data availability statement

The data generated and/or analysed during the current study are not publicly available for legal/ethical reasons but are available from the corresponding author on reasonable request.

ORCID iDs

Jukka Heinonen https://orcid.org/0000-0002-7298-4999

References

Aamaas B, Borken-Kleefeld J and Peters G P 2013 The climate impact of travel behavior: A German case study with illustrative mitigation options *Environ. Sci. Policy* **33** 273–82

Afionis S, Sakai M, Scott K, Barrett J and Gouldson A 2017 Consumption-based carbon accounting: does it have a future? *WIREs Climate Change* **8** e438

Akenji L, Bengtsson M, Toivio V, Lettenmeier M, Fawcett T, Parag Y, Saheb Y, Coote A, Spangenberg J H and Capstick S 2021 *Degree Lifestyles: Towards A Fair Consumption Space for All.* **1** 5

Ala-Mantila S, Ottelin J, Heinonen J and Junnila S 2016 To each their own? The greenhouse gas impacts of intra-household sharing in different urban zones *J. Clean. Prod.* **135** 356–67

Alhola K, Mäenpää I, Nissinen A, Nurmela J, Salo M and Savolainen H 2019 Carbon footprint and raw material requirement of public procurement and household consumption in finland—results obtained using the ENVIMAT-model Ed ed A Nissinen and H Savolainen *Suomen Ympäristökeskuksen Raportteja* 15; 2019 (Helsinki: Finnish Environmental Institute (SYKE)) 33

Árnadóttir Á, Czepkiewicz M and Heinonen J 2021 Climate change concern and the desire to travel: How do I justify my flights? *Travel Behaviour and Society* **24** 282–90

Barros B and Wilk R 2021 The outsized carbon footprints of the super-rich *Sustainability: Science, Practice and Policy* **17** 316–22

Baynes T M and Wiedmann T 2012 General approaches for assessing urban environmental sustainability *Current Opinion in Environmental Sustainability* **4** 458–64

Chen G, Hadjikakou M, Wiedmann T and Shi L 2018 Global warming impact of suburbanization: the case of sydney *J. Clean. Prod.* **172** 287–301
Cherubini F, Bird N D, Cowie A, Jungmeier G, Schlamadinger B and Woess-Gallasch S 2009 Energy-and greenhouse gas-based LCA of biofuel and bioenergy systems: Key issues, ranges and recommendations *Resour. Conserv. Recycl.* **53** 434–47
Chester M V and Horvath A 2009 Environmental assessment of passenger transportation should include infrastructure and supply chains *Environ. Res. Lett.* **4** 024008
Clarke J, Heinonen J and Ottelin J 2017 Emissions in a decarbonised economy? global lessons from a carbon footprint analysis of Iceland *J. Clean. Prod.* **166** 1175–86
Claudelin A, Uusitalo V, Hintukainen I, Kuokkanen A, Tertsunen P, Leino M and Linnanen L 2020 Increasing positive climate impact by combining anti-consumption and consumption changes with impact investing *Sustainable Development* **28** 1689–701
Creutzig F, Niamir L, Bai X, Callaghan M, Cullen J, Díaz-José J, Figueroa M, Grubler A, Lamb W F and Leip A 2022a Demand-side solutions to climate change mitigation consistent with high levels of well-being *Nat. Clim. Change* **12** 36–46
Creutzig F, Roy J, Devine-Wright P, Diaz-José J, Geels F, Grubler A, Maïzi N, Masanet E, Mulugetta Y and Onyige-Ebeniro C 2022b Demand, services and social aspects of mitigation *IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* (UK: Cambridge University Press)
Czepkiewicz M, Árnadóttir Á and Heinonen J 2019 Flights dominate travel emissions of young urbanites *Sustainability* **11** 6340
Czepkiewicz M, Ottelin J, Ala-Mantila S, Heinonen J, Hasanzadeh K and Kyttä M 2018 Urban structural and socioeconomic effects on local, national and international travel patterns and greenhouse gas emissions of young adults *Journal of Transport Geography* **68** 130–41
Dubois G, Sovacool B, Aall C, Nilsson M, Barbier C, Herrmann A, Bruyère S, Andersson C, Skold B and Nadaud F 2019 It starts at home? climate policies targeting household consumption and behavioral decisions are key to low-carbon futures *Energy Research & Social Science* **52** 144–58
Eurostat 2022 Living conditions in Europe - income distribution and income inequality *Statistics Explained Retrieved* **7** 10.2022 2022
Girod B, Van Vuuren D P and Hertwich E G 2014 Climate policy through changing consumption choices: Options and obstacles for reducing greenhouse gas emissions *Global Environ. Change* **25** 5–15
Gössling S and Dolnicar S 2022 A review of air travel behavior and climate change *Wiley Interdiscip. Rev. Clim. Change* e802
Gram-Hanssen K, Christensen T H and Petersen P E 2012 Air-to-air heat pumps in real-life use: Are potential savings achieved or are they transformed into increased comfort? *Energy Build.* **53** 64–73
Green F and Healy N 2022 How inequality fuels climate change: the climate case for a green new deal *One Earth* **5** 635–49
Hasegawa R, Kagawa S and Tsukui M 2015 Carbon footprint analysis through constructing a multi-region input–output table: a case study of Japan *Journal of Economic Structures* **4** 1–20
Heinonen J, Jalas M, Juntunen J K, Ala-Mantila S and Junnila S 2013 Situated lifestyles: I. How lifestyles change along with the level of urbanization and what the greenhouse gas implications are—a study of Finland *Environ. Res. Lett.* **8** 025003
Heinonen J and Junnila S 2011 Implications of urban structure on carbon consumption in metropolitan areas *Environ. Res. Lett.* **6** 014018
Heinonen J, Kyrö R and Junnila S 2011 Dense downtown living more carbon intense due to higher consumption: a case study of Helsinki *Environ. Res. Lett.* **6** 034034
Heinonen J, Ottelin J, Ala-Mantila S, Wiedmann T, Clarke J and Junnila S 2020 Spatial consumption-based carbon footprint assessments - a review of recent developments in the field *J. Clean. Prod.* **256**
Heinonen J, Ottelin J, Guddisardottir A K and Junnila S 2022 Spatial consumption-based carbon footprints: two definitions, two different outcomes *Environmental Research Communications* **4** 025006
Herrera-Camacho J, Baltierra-Trejo E, Taboada-González P A, Gonzalez L F and Márquez-Benavides L 2017 (https://doi.org/10.20944/preprints201707.0004.v1)
Hertwich E G and Peters G P 2009 Carbon footprint of nations: a global, trade-linked analysis *Environmental Science & Technology* **43** 6414–20
Hubacek K, Baiocchi G, Feng K, Muñoz Castillo R, Sun L and Xue J 2017 Global carbon inequality *Energy, Ecology and Environment* **2** 361–9
IPCC 2021 Climate Change 2021: the physical science basis *Contribution of working group 1 to the sixth assessment report of the intergovernmental panel on climate change.* ed V Masson-Delmotte *et al* (Cambridge: Cambridge University Press)
IPCC 2022 Climate change 2022: mitigation of climate change. *Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change.* ed P R Shukla *et al* (Cambridge: Cambridge University Press) (https://doi.org/10.1017/9781009157926.001)
Institute for Global Environmental Strategies (IGES), Aalto University, and D-mat Ltd 2019 1.5-Degree lifestyles: targets and options for reducing lifestyle carbon footprints *Technical Report.* (Hayama, Japan: Institute for Global Environmental Strategies)
Ivanova D, Barrett J, Wiedenhofer D, Macura B, Callaghan M and Creutzig F 2020 Quantifying the potential for climate change mitigation of consumption options *Environ. Res. Lett.* **15** 093001
Ivanova D, Stadler K, Steen-Olsen K, Wood R, Vita G, Tukker A and Hertwich E G 2016 Environmental impact assessment of household consumption *J. Ind. Ecol.* **20** 526–36
Jaccard I, Pichler P, Többen J and Weisz H 2021 The energy and carbon inequality corridor for a 1.5 °C compatible and just Europe *Environ. Res. Lett.* **16** 064082
Jokinen J, Nilsson K, Karlsdóttir A, Heleniak T, Kull M, Stjernberg M, Borges L A, Norlén G, Randall L and Grunfelder J 2020 State of the Nordic Region 2020, Nordic Council of Ministers (https://norden.org/en/nordicregion2020)
Jones C and Kammen D M 2014 Spatial distribution of US household carbon footprints reveals suburbanization undermines greenhouse gas benefits of urban population density *Environmental science & technology* **48** 895–902
Kanemoto K, Moran D, Lenzen M and Geschke A 2014 International trade undermines national emission reduction targets: New evidence from air pollution *Global Environ. Change* **24** 52–9
Koide R, Kojima S, Nansai K, Lettenmeier M, Asakawa K, Liu C and Murakami S 2021a Exploring carbon footprint reduction pathways through urban lifestyle changes: a practical approach applied to Japanese cities *Environ. Res. Lett.* **16** 084001
Koide R, Lettenmeier M, Akenji L, Toivio V, Amellina A, Khodke A, Watabe A and Kojima S 2021b Lifestyle carbon footprints and changes in lifestyles to limit global warming to 1.5 °C, and ways forward for related research *Sustainability Sci.* **16** 2087–99
Lee D S, Fahey D, Skowron A, Allen M, Burkhardt U, Chen Q, Doherty S, Freeman S, Forster P and Fuglestvedt J 2021 The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018 *Atmos. Environ.* **244** 117834
Mach R, Weinzettel J and Ščasný M 2018 Environmental Impact of consumption by czech households: hybrid input–output analysis linked to household consumption data *Ecol. Econ.* **149** 62–73
Mattioli G, Roberts C, Steinberger J K and Brown A 2020 The political economy of car dependence: A systems of provision approach *Energy Research & Social Science* **66** 101486

Maxim A, Mihai C, Apostoaie C-M, Popescu C, Istrate C and Bostan I 2016 Implications and measurement of energy poverty across the european union *Sustainability* **8** 483
Minx J, Baiocchi G, Wiedmann T, Barrett J, Creutzig F, Feng K, Förster M, Pichler P-P, Weisz H and Hubacek K 2013 Carbon footprints of cities and other human settlements in the UK *Environ. Res. Lett.* **8** 035039
Mundaca L, Ürge-Vorsatz D and Wilson C 2019 Demand-side approaches for limiting global warming to 1.5 °C *Energ. Effic.* **12** 343–62
Ottelin J 2016 Rebound effects projected onto carbon footprints - Implications for climate change mitigation in the built environmentAalto University publication series DOCTORAL DISSERTATIONS, 219/2016 (https://aaltodoc.aalto.fi/handle/123456789/23070)
Ottelin J, Ala-Mantila S, Heinonen J, Wiedmann T, Clarke J and Junnila S 2019 What can we learn from consumption-based carbon footprints at different spatial scales? review of policy implications *Environ. Res. Lett.* **14** 093001
Ottelin J, Cetinay H and Behrens P 2020 Rebound effects may jeopardize the resource savings of circular consumption: evidence from household material footprints *Environ. Res. Lett.* **15** 104044
Ottelin J, Heinonen J and Junnila S 2015 New energy efficient housing has reduced carbon footprints in outer but not in inner urban areas *Environmental Science & Technology* **49** 9574–83
Ottelin J, Heinonen J and Junnila S 2017 Rebound effects for reduced car ownership and driving *Nordic Experiences of Sustainable Planning.* (UK: Routledge) Chapter in a book: Nordic Experiences of Sustainable Planning: Policy and Practice, Publisher: Routledge, Editors: Sigríður Kristjánsdóttir.
Research Centre of Finland Ltd LIPASTO unit 2021 emissions -database. (Accessed 16.6) Available at: lipasto.vtt.fi/yksikkopaastot/
Saarinen M K *et al* 2019 *Effects of dietary change and policy mix supporting the change -End report of the FoodMin project.* (Helsinki: Publications of the Government´s analysis, Assessment and Research Activities 2019)
Salo M and Nissinen A 2017 (https://sitra.fi/en/publications/consumption-choices-decrease-personal-carbon-footprints-finns/)
Seibert M K and Rees W E 2021 Through the eye of a needle: an eco-heterodox perspective on the renewable energy transition *Energies* **14** 4508
Sörqvist P and Langeborg L 2019 Why people harm the environment although they try to treat it well: An evolutionary-cognitive perspective on climate compensation *Frontiers in psychology* **10** 348
Sorrell S, Gatersleben B and Druckman A 2020 The limits of energy sufficiency: A review of the evidence for rebound effects and negative spillovers from behavioural change *Energy Research & Social Science* **64** 101439
Stadler K, Wood R, Bulavskaya T, Södersten C J, Simas M, Schmidt S and Tukker A 2018 EXIOBASE 3: Developing a time series of detailed environmentally extended multi-regional input-output tables *J. Ind. Ecol.* **22** 502–15
United Nations 2018 Classification of individual consumption according to purpose (COICOP) 2018 *Statistical Papers. Department of Economic and Social Affairs. Statistics Division* (United Nations, New York: United Nations Publication) Series M No. 99 265
Vimpari J 2021 Should energy efficiency subsidies be tied into housing prices? *Environ. Res. Lett.* **16** 064027
Vita G, Lundström J R, Hertwich E G, Quist J, Ivanova D, Stadler K and Wood R 2019 The Environmental impact of green consumption and sufficiency lifestyles scenarios in europe: connecting local sustainability visions to global consequences *Ecol. Econ.* **164** 106322
Van Vuuren D P, Stehfest E, Gernaat D E, Van Den Berg M, Bijl D L, De Boer H S, Daioglou V, Doelman J C, Edelenbosch O Y and Harmsen M 2018 Alternative pathways to the 1.5 C target reduce the need for negative emission technologies *Nat. Clim. Change* **8** 391–7
Wiedenhofer D, Guan D, Liu Z, Meng J, Zhang N and Wei Y-M 2017 Unequal household carbon footprints in China *Nat. Clim. Change* **7** 75–80
Wiedmann T, Lenzen M, Keyßer L T and Steinberger J K 2020 Scientists' warning on affluence *Nat. Commun.* **11**
Wood R, Stadler K, Simas M, Bulavskaya T, Giljum S, Lutter S and Tukker A 2018 Growth in environmental footprints and environmental impacts embodied in trade: resource efficiency indicators from EXIOBASE3 *J. Ind. Ecol.* **22** 553–64
Wynes S and Nicholas K A 2017 The climate mitigation gap: education and government recommendations miss the most effective individual actions *Environ. Res. Lett.* **12** 074024
Yavor K M, Lehmann A and Finkbeiner M 2020 Environmental impacts of a pet dog: an LCA case study *Sustainability* **12** 3394