The impact of low-carbon consumption options on carbon footprints in the Nordic region

Abstract

Changes in personal consumption play an important role in the reduction of greenhouse gasses (GHGs) to stay within the 1.5 degree warming carbon footprint budget. Affluent countries have high carbon footprints from a consumptive perspective and therefore have a high potential to reduce emissions from personal consumption. To study this potential, we look at the consumption-based carbon footprints of respondents from a carbon footprint calculator survey from the Nordic countries to compare the carbon footprints of those who participated in selected low-carbon consumption options to those that did not. The total sample size of the survey is 8,000 households. We analyzed seven low-carbon consumption options within the domains of diet, transportation, and housing energy. An input-output based hybrid assessment model was used to calculate the consumption-based carbon footprints. In addition to analyzing these options separately, we also analyzed them in combination. The lowest carbon footprints were associated with those respondents who participated in not owning a car or having a vegan or vegetarian diet and the largest difference in emissions was associated with not flying and not owning a car. Rebound effects for the consumption options were largely limited and were mostly not significant. Participation rates in the low-carbon consumption options were generally low. These results underscore the need for higher rates of adopting multiple low-carbon consumption options and can inform policy on which consumption options could be the most impactful.

1. Introduction

To limit global warming to 1.5°C, deep and immediate reductions in greenhouse gas (GHG) emissions are necessary (IPCC, 2022). The challenge of reducing GHG emissions requires actions from all parts of society, not only technological and systemic changes, but also changes in lifestyle (Capstick et al., 2020, IPCC, 2022). Recent reports have highlighted the importance of demand-side measures for climate change mitigation (IPCC, 2022, Capstick et al., 2020, Akenji et al., 2021). Since more than 60% of GHG emissions can be attributed to household consumption (Ivanova et al., 2016), there is great potential for climate change mitigation through demand-side actions. Although there is great potential for changes in lifestyle and consumption to decrease GHG emissions, people often face barriers to taking pro-climate actions such as being limited by the infrastructure and built environment around them, existing energy and economic systems, food production methods, and social values and practices (Newell et.al, 2021). Understanding more about how consumption patterns and the mitigation potential of low-carbon consumption options (LCCOs) affect carbon footprints can help with realizing the potential mitigation of demand-side actions.

Among the affluent countries, the need for reductions in GHG emissions caused by private consumption is substantial. In developed countries, it is estimated that consumption-based carbon footprints (CBCFs) need to be reduced by 60-80% by 2030 and 80-90% by 2050 (Koide et al., 2021b). Affluent individuals are also overconsuming with the top 10% of income earners estimated at being responsible for 36-49% of global emissions, whereas the bottom 50% of income earners are responsible for around 7-15% of emissions (Capstick et al., 2020, Wiedmann et al., 2020, Hubacek et al., 2017). It is important to understand these inequities and to identify groups with high and low carbon footprints in order to create fair pathways toward 1.5 degree compatible lifestyles (Capstick et al., 2020). The report from Akenji et al. (2021) proposes a way to fairly distribute the remaining carbon budget to meet the 1.5°C goal of the Paris Agreement. This report aligns with other studies such as the current footprint per capita from Ivanova et al. (2016) and the IPCC pathways (IPCC, 2021) and has set the limit for per capita CBCFs at 2.5 tCO_2e for 2030 and 0.7 tCO_2e for 2050 (Akenji et al., 2021). The current world average is around 3.4 tCO_2e per capita for the emissions driven by personal consumption, but CBCFs are not equally distributed globally and the footprints in wealthy nations are much higher (Ivanova et al., 2016; Hubacek et al., 2017). Therefore, while the emissions caused by the residents of the affluent countries need to decline rapidly, there can still be growth in those caused by the lower income nations if the remaining carbon budget was equally distributed across the globe (Ala-Mantila et al. 2023).

CBCFs have become a valuable tool for studying climate change mitigation options from a consumer perspective (Ottelin et al., 2019, Heinonen et al., 2020). CBCFs allocate emissions from consumption to the end user regardless of where the good or service was produced, which can be beneficial to climate change mitigation from a consumption perspective by accounting for emissions embodied in global trade (Afionis et al., 2017). Up to one third of global emissions are embodied in internationally traded goods (Kanemoto et al., 2014, Wood et al., 2018). Affluent nations are often net importers of emissions, so CBCFs can provide a more accurate measurement of their global climate impact than the traditional territorial assessments (Afionis et al., 2017). It is common practice to not include government spending and capital formation in personal CBCFs (Heinonen et al., 2020), which can make it possible to link emission limits to individuals' actions therefore identifying ways that people can decarbonize their lifestyles (Koide et al., 2021a). Researchers have utilized CBCFs to quantify potential reductions in emissions due to lifestyle changes and have found great mitigation potential in the areas of diet, transportation, and home energy (Bjelle et al., 2018, Ivanova et al., 2020, Koide et al., 2021a, Jones and Kammen, 2011).

These studies have found that if consumers make multiple changes in these domains and other areas of consumption, then this can lead to significant decreases in their overall carbon footprint (Jones and Kammen, 2011, Koide et al., 2021a, Salo and Nissinen, 2017, Ivanova et al., 2020). For example, Ivanova et al. (2020), through a systematic literature review, found that the top ten LCCOs had the mitigation potential of 9.2 tCO_2e per capita. Salo and Nissinen (2017), estimated that the average Finnish consumer could reduce their carbon footprint by 4.3 tCO_2e with the current existing technology and solutions available. The rebound effect, which can reduce the impact of lifestyle changes , is not always included in studies, and some authors have been skeptical about the potential embedded in lifestyle changes due to these rebound effects (Nässén et al., 2015; Ottelin et al., 2017). The rebound effect occurs when money is saved from efficiency gains or from decreases in one consumption category and then is re-spent on other GHG emitting consumption domains, thus decreasing the effectiveness of money-saving, demand-side actions (Ottelin, 2016, Bjelle et al., 2018). For example, Bjelle et al. (2018) found that households in Norway could reduce their carbon footprints by up to 58% by implementing a set of low-carbon actions, but when taking into account the potential rebound effect, the reduction potential dropped to 24-35%. Similarly, Ottelin et al. (2020) found a strong rebound effect in Finland among people that did not possess and operate a private car, which led to more spending on other consumption, and particularly on leisure travel, with the result of those not possessing vehicles not having the lowest footprints.

This study focuses on the Nordic countries, including Denmark, Finland, Iceland, Norway, and Sweden. The Nordic countries have similar social and economic systems (the Nordic welfare system), they are highly affluent, yet they have low income inequality, and they are often seen as “green” countries (Wolf et al., 2022), although they have high CBCFs (Jokinen et al., 2020, Ivanova et al., 2016, Clarke et al., 2017, Hubacek et al., 2017; Heinonen et al. 2022). Some of the Nordic countries have highly decarbonized energy systems for heating and electricity, such as in Iceland, where the energy mix is 99% renewable (Orkustofnun, 2015). Yet despite this highly decarbonized energy system, the CBCFs of Iceland are similar to that of the other most wealthy European nations (Clarke et al., 2017). A large portion of the emissions in the Nordic countries can be attributed to emissions from imported goods and services (Jokinen et al., 2020, Ivanova et al., 2016). For example, in Sweden, 65% of household emissions are embodied in imports (Ivanova et al., 2016) and in Iceland it has been estimated to be around 71% (Clarke et al., 2017). The Nordic countries make for an interesting case to study since affluent individuals contribute disproportionately to GHG emissions and they have the most potential for emission reductions (IPCC, 2022), and in the Nordic countries even the lower income segment is highly affluent in global terms, and the footprint difference to the higher income segments is only moderate (Heinonen et al. 2022).

This study adds to this field of research by using empirical data from a carbon footprint calculator survey (Heinonen et al. 2022), which reveals the rates of participation in the selected LCCOs of the respondents and their overall consumption patterns as they relate to their personal consumption-based carbon footprint. A recent study from Andersson and Nässén (2023) looked at the effect of four LCCOs on carbon footprints based on participants’ purchases from bank data in combination with a lifestyle survey in Sweden. Our study provides a point of comparison to this Swedish study, and we calculate the carbon footprints using not only monetary expenditure, but also with the physical quantity of consumption while also expanding the scope across all the Nordic countries. It also continues the study of LCCOs and their potential effect on CBCFs in the Nordic countries from Heinonen et al. (2022).

The study has two main novelty value aspects. First, the footprints are calculated mainly based on physical quantities instead of monetary values. This has been shown to reduce the typically found strong income elasticity of footprints (Leferink et al. 2023), and no studies so far have tested the impacts of LCCOs with such data. Second, our method inherently includes rebound effects which are often excluded from LCCO studies (Ivanova et al.2020). Furthermore, the mainly physical quantities -based calculation method does not suffer from the typical linearity and homogeneity assumptions in input-output analysis-based carbon footprint studies (Heinonen et al. 2020), which may explain why the found rebound effects are smaller than some of the previous estimates (Ottelin et al. 2017). In addition, the impacts of LCCOs found in previous studies vary significantly, indicating that more research is needed to better understand the impact mechanisms.

In this study, we aim to answer the research questions:

- Do the personal CBCFs of those participating in a low-carbon consumption option differ from those who do not?

- Do the selected low-carbon consumption options have a rebound effect?

To study this, we utilize data from a carbon footprint calculator survey conducted in the Nordic countries to calculate and compare the personal CBCFs of those who participated in the LCCOs of having a vegan or vegetarian diet, buying renewable electricity for the home, having a heat pump, not owning a car, driving an electric vehicle (EV), using public transportation, and not flying to those who did not. Regression analysis was used to better isolate the impact associated with each LCCO and see the significance of any rebound effects. Additionally to analyzing these LCCOs separately, we also analyzed them in combination since often participating in only one of these consumption options in the Nordic context will not result in footprints that align with a 1.5 degree lifestyle (Heinonen et al., 2022).

2. Methods

2.1 Carbon footprint calculator survey

Our study is based on a carbon footprint calculator survey which was conducted between the autumn of 2021 and the spring of 2022, which received around 8,000 full responses (Heinonen et al., 2022; carbonfootprint.hi.is). The respondents were all adult residents of one of the Nordic countries including Denmark (511), Finland (2064), Iceland (1538), Norway (1285), and Sweden (1962). They were asked a variety of questions about their consumption over the past year to calculate their personal CBCFs. The respondents were also asked questions about their climate attitudes, pro-climate actions, general well-being, and other socio-demographic factors. The survey was available in English, along with the main languages in each country (Finnish, Swedish, Norwegian, Danish, Icelandic, and Polish). The aim of the survey was to collect enough data to be able to identify those who are participating in LCCOs or are living a 1.5 degree compatible lifestyle, not to be representative of the population as a whole. More detailed information about the survey collection can be seen in Heinonen et al., (2022).

2.2 Baselines for low-carbon consumption options

As a baseline of comparison for our study, we identified the estimated reduction potential of different consumption options in multiple recent studies. First, we looked at studies that focused on CBCFs along with the reduction potential of the demand-side consumption options. Then we narrowed our focus to the studies that were based on countries with a similar level of affluence as the Nordic countries, with the exception of one world-wide study where we utilized the average reduction potential, and compared mitigation options on a per capita basis. The LCCOs we investigated were chosen by matching options from our survey to the consumption options that showed high reduction potential in the literature reviewed. Studies which are not comparable to our results, such as those looking at the household footprints rather than per capita footprints, or those which group together choices to show the impact on one domain rather than listing the individual reduction potential of each option were not included in our baseline comparison. Table 1 shows the ranges of mitigation potential found in the studies for different consumption options, as well as their location, methodology, data and if the rebound effect was considered.

Table 1. Range of mitigation potential from LCCOs in consumption-based carbon footprint studies in tCO_2e.

Study	Andersson & Nässén 2023	Carlsson Kanyama et al., 2021^	Ivanova et al., 2020 (average)	Koide et al., 2021a*	Koide et al., 2021b**	Total Range

Location	Sweden	Sweden	World-wide	Japanese cities	Finland and Japan	
Methods	Input-output approach	Hybrid input-output approach with Environmental Analysis Program (EAP)	Meta-review of 53 studies using LCA or multiregional input-output methods	Input-output approach	LCA and input-output models	
Main data	Financial data from bank transactions & lifestyle survey	Household expenditure survey	Literature review	Family and income expenditure survey	National statistics to estimate physical consumption	
Rebound effect considered	Yes	Yes	No	Yes	No	
Vegan or vegetarian diet	1.5 (vegan)	0.3-0.5 (replacing meat & dairy with plant products, local vegetables)	0.5 (vegetarian) 0.9 (vegan)	0.2-0.3 (vegetarian) 0.3-0.4 (vegan)	0.3-0.9 (vegetarian)	0.2-1.5
Renewable electricity			1.5	0.9-2.0	0.6-1.3	0.6-2.0
Heat pump			0.8	0.07-0.2	0.09-0.6	0.07-0.8
No car	0.5		2.3		0.7-1.6	0.5-2.3
EV			2.0	0.06-0.8	0.5-1.1	0.06-2.0
No flights (less flights for leisure)	1.5 (no flying)	0.8-0.9 (replacing flights abroad with train travel)	0.8 (less transport by air)		0.1-0.4 (reduction of flights)	0.1-1.5
Public transport			1.0		0.2-0.4	0.2-1.0

^Mitigation range of average person, man, woman
*Mitigation range between Japanese cities
**Mitigation range between Finland and Japan

2.3 Calculation of carbon footprints

The per capita footprints were calculated with an advanced input-output hybrid assessment model where the majority of the footprint is assessed with the physical quantity of consumption and only a minor share with a direct monetary-based input-output approach using the Exiobase model, as described in detail in Heinonen et al. (2022). Only the personal component of consumption was focused on, so government spending and capital formation were not included in the carbon footprints. The carbon footprints were calculated based on the survey respondents' estimation of their private consumption over the past year and were divided into eight domains including: diet, housing energy, private vehicle possession and use, public transport, leisure travel, goods and services, pets, and second homes. Shared consumption domains such as housing energy, private vehicle possession and use, pets, and second homes were divided by the number of people living in the household. The sum of the eight domains equal the overall or total carbon footprint. The approach and data sources used to calculate the footprint domains associated with the selected LCCOs are described below and full details of the carbon footprint calculations can be found in Heinonen et al., (2022) as well as in the supplemental section titled "Calculation pathways for footprint domains".

Diet

The survey respondents were asked to describe their diets with the one of the following options: vegan, vegetarian, pescatarian, or omnivore with options to describe their weekly meat intake. The values of GHG emissions associated with each diet were taken from Saarinen et al. (2019).

Housing energy

To calculate the GHG emissions associated with housing energy, respondents were asked about the size of their home, the decade it was built, its heating mode, and its source of electricity. The emission factors for home energy electricity are based on each country's electricity mix, and the average GHG emissions for each electricity source are taken from Cherubini et al. (2009), which includes scope 1-3 emission factors. Iceland and Norway have electricity mixes that are almost 100% renewable (Orkustofnun, 2015, Statistics Norway, 2020). Therefore, since consumers are already receiving renewable electricity in their homes and not actively choosing to purchase it, this consumption option was not included in the analysis for Iceland and Norway. For this analysis, only respondents who chose heat pumps as their main heat source were considered in the comparison to better see the impact from having a heat pump.

Vehicles possession and use

The respondents were asked to report, for each vehicle in the household, the type of vehicle, fuel type, fuel efficiency (liter/100km), and distance driven in the past year. The emission factors per liters combusted for each fuel type were calculated from Cherubini et al. (2009) including scopes 1-3. The production and maintenance of vehicle ownership was added to the vehicle use emissions to better capture the emissions associated with vehicle ownership. To calculate the emissions from the production and maintenance of vehicles, we used values from the review of Dillman et al. (2020) and divided these values with the average lifetime kilometers driven and then multiplied this by the reported distance driven. The overall vehicle-related emissions were then divided by the household size. If the respondents reported zero cars in the household, then they were considered as not possessing a car and therefore had zero emissions for the vehicle use and possession domain.

Public transportation

Survey respondents were asked to report the weekly average number of kilometers that they traveled by public transportation in the past year. An average intensity was based on indirect emissions from Chester and Horvath (2009) and direct emissions from VTT Technical Research Centre of Finland 2021. People who reported using public transportation on a weekly basis were included in this analysis as public transportation users.

Leisure travel

Survey respondents were asked about their leisure travel over the past year and asked to report the number of short (0-1000 km), medium (1000-3000 km), and long (3000 km+) distance leisure trips by ferry, plane, train, bus, or car. In our analysis, we compare those respondents who reported taking leisure flights to those that did not. To calculate the emissions from flying, factors were calculated based on Chester and Horvath (2009) for the indirect component and Aamaas et al. (2013) for the direct component assuming typical occupancy.

2.4 Bivariate and Regression Analysis

To compare the overall carbon footprints of those who participated in the selected LCCOs compared to those who did not participate, we calculated the average carbon footprints for each group. To calculate the difference in the carbon footprints between those that participated in the LCCO and those that did not, we subtracted the average carbon footprint from the group that did not participate from the group that did.

To control for the effects that income, household size, degree of urbanization, age, gender, and level of education can have on carbon footprints, multivariable regression models were utilized. The general regression model is:

$$\ln (CF) = \beta_0 + \beta_1 D_1 + \ldots \beta_n D_n + u$$

Where CF = carbon footprint, β_0 = constant term, β_1 to β_n = regression coefficients, D_1 to D_n = dummy variables and u = error term

Table 2. Explanation of variables used in regression analysis and percentage of respondents in the sample who participate in each LCCO or belong to each sociodemographic group

Variable	Explanation	Percentage of respondents	Description
Dependent Variable			
Carbon footprint	ln(carbon footprint)		Annual total carbon footprint
Low-carbon consumption options			
Vegan/ vegetarian	1: vegan or vegetarian 0: not vegan or vegetarian	14% 86%	Vegan or vegetarian was chosen for diet type
No car & EV	No car_dummy EV_dummy Other fuels_dummy	22% 10% 68%	Reported not owning a car Primary vehicle reported as an EV Primary vehicle reported as a fossil fuel or other fuel vehicle
Heat pump	1: heat pump 0: no heat pump	16% 84%	Reported heat pump as primary home heating source. Only compared in detached homes.
Public transportation	1: public transportation use 0: no public transportation use	41% 59%	Reported using public transportation (in km) on a weekly basis
Renewable electricity	1: renewable electricity 0: no renewable electricity	73% 27%	Reported purchasing renewable electricity for the home. Iceland and Norway not included.
No flights	1: no flights 0: flights taken	77% 23%	No flights were reported in leisure travel

Income	Income_low_dummy Income_med_dummy Income_high_dummy	35% 31% 34%	11 income groups categorized as low (1-3), medium (4-7), and high (8-11)
Household type	Single_dummy couple_dummy single_parent_dummy couple_children_dummy	28% 42% 4% 26%	Household type based on reported number of adults and children living in the household.
Degree of urbanization	Urban_dummy Towns_and_suburbs_dummy Rural_dummy	48% 28% 23%	The degree of urbanization according to Eurostat 2018 assessment
Age	Ages_15 to 40_dummy Ages_41 to 54_dummy Ages_55 to 80_dummy	32% 26% 42%	Reported ages grouped to create three similar sized groups
Gender identity	Male_dummy Female_dummy Nonbinary_other_dummy	37% 61% 2%	Reported gender grouped as male, female, and non-binary/other
Education level	Basic_secondary_dummy College_vocational_dummy Grad_postgrad_dummy	19% 43% 38%	Highest reported education grouped as basic and secondary, vocational and college, graduate and post-graduate

To estimate the potential rebound effects, we compared the difference in the overall footprint between the groups taking part in or not each LCCO to the difference in the corresponding domain, as listed in Section 2.1, to see if the difference in the domain was greater than the difference in the overall carbon footprint. If it was, then this was considered a potential rebound. It should be noted that it is a rough estimate, as the differences may arise from other differences between the studied groups as well. To test for the significance of the potential rebound and to control for effects of other sociodemographic factors, we used linear regression. To do this in a regression setting, we took the rest of the footprint without the domain in question and checked if participation in the consumption option increases the remainder of the footprint.

For those with high carbon footprints, it often takes multiple changes in consumption patterns and behaviors to reduce footprints to 1.5-degree compatible levels (Heinonen et al., 2022, Koide et al., 2021a). Therefore, we also analyzed the average carbon footprint of those participating in two of the LCCOs, and dummy variables were created to compare the CBCFs for those who participated in both options, one option or none using linear regression. Each combination of two LCCOs was analyzed with the exception of not owning a car and driving an EV. The footprint of the combination of two of each of the LCCOs was also calculated.

3. Results

3.1 Limited rebounds, low participation, and which LCCOs are associated with low carbon footprints

When comparing those who participated in the selected LCCOs to those that did not, the options that were associated with lowest overall footprints in each country were from those who did not own a car or from those who had reported having a vegan or vegetarian diet. The biggest difference in the overall carbon footprints was associated with those who took flights and those that did not followed by not owning a car. Figure 1 shows the carbon footprints, the difference, and the participation percentages associated with each LCCO. More details about the carbon footprint ranges can be seen in the Supplemental Section in Figure A.

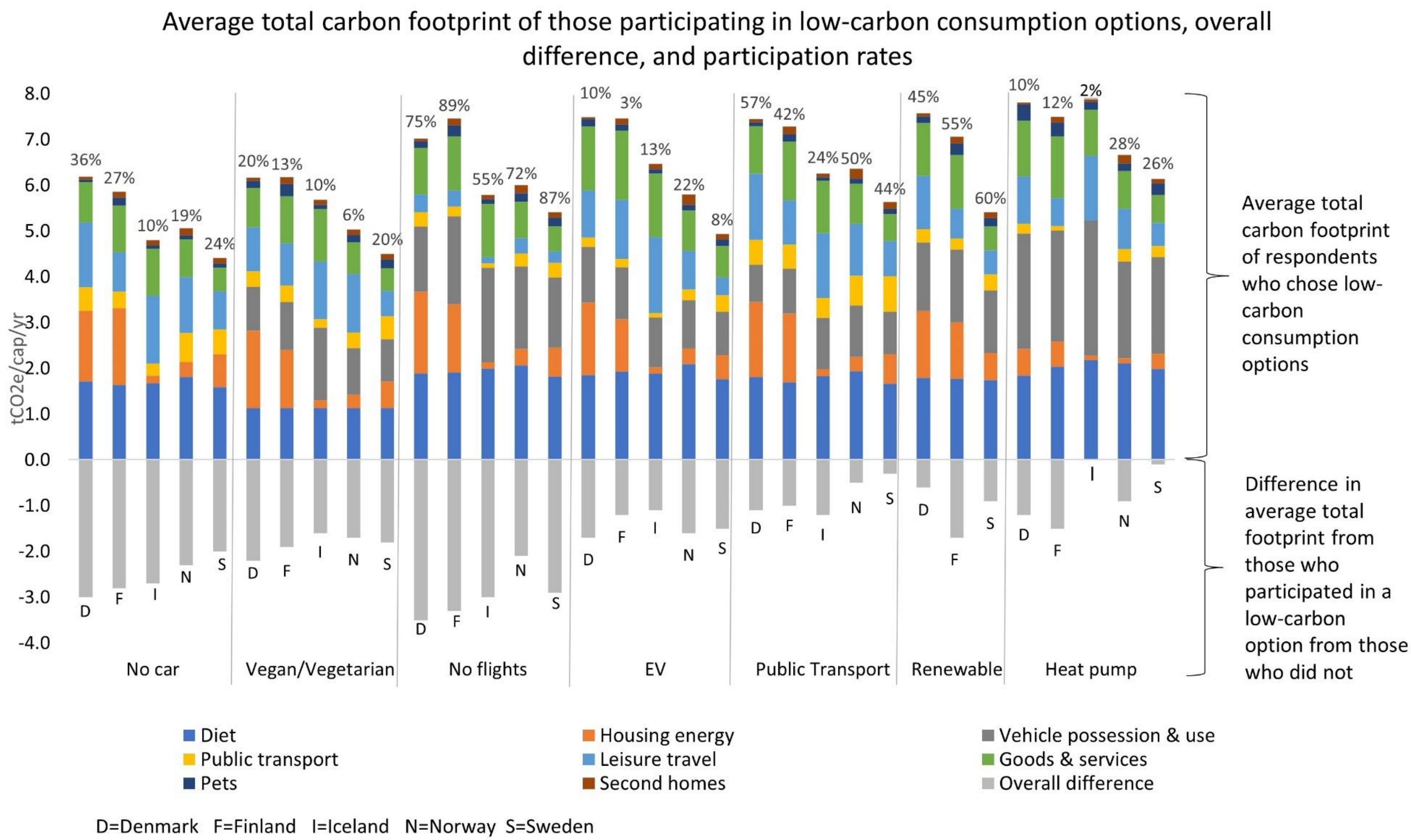

Figure 1. Shows the total carbon footprint per capita, including the domains, associated with those who participated in a LCCO. The difference between the overall carbon footprint of those who did not participate in a LCCO and those that did. The percentage of respondents who participated in each of the LCCOs is included above the carbon footprint bar.

In Figure 1, the differences in the housing energy domain can be seen across the different countries due to the different energy mixes in each country. Having a heat pump was found to be associated with footprints over one ton lower than in the comparison group in Denmark and Finland, but as much less important in the countries with more decarbonized energy mixes (Iceland, Norway and Sweden), to the extent that the average carbon footprint of those with a heat pump in Iceland was even slightly larger than those who did not. Slightly higher average vehicle emissions were mostly associated with participants who took no flights and owned heat pumps than the participants in the other LCCOs as well as slightly higher emissions from leisure travel can be seen in those who do not own cars and public transportation users. The LCCOs with the highest participation were no flights (55-89%), renewable electricity (45-60%) and public transport use (24-57%). Participation in the LCCOs was generally lower in Iceland than the other countries especially in some of the transport related LCCOs (with the exception of driving an EV) since Iceland has a less developed public transportation than the other countries and no alternative to flights to travel abroad. LCCO participants from Sweden had the lowest footprints on average as compared to the other countries whereas Denmark and Finland had higher footprints.

Bivariate analysis revealed that rebound effects occurred in the average total footprints of those who did not own a car (Sweden), took no flights (Norway), drove an EV (Finland and Iceland), and had a heat pump (Denmark, Iceland, Sweden). Linear regression confirmed that these rebounds were small (regression coefficients less than 0.1) and not significant except for not owning a car in Sweden

When comparing the mitigation potential from the LCCOs found in the literature to the difference decreases in carbon footprints seen between those who participated in LCCOs to those who did not, buying renewable electricity for the home, driving an EV, and public transportation use matched up with the ranges that were found within the literature. The difference between the carbon footprints of those who participated in being a vegan or vegetarian, not owning a car, and taking no flights to those that did not, exceeded the range of mitigation potential identified in the literature. Having a heat pump led to footprints that were both higher and lower than those who did not have a heat pump and the difference was both higher and lower than what was found in the literature.

When controlling for socio-economic qualities (see Table 2), we can observe the regression coefficients (unstandardized beta) for the LCCOs for each country in Figure 2. The control variables are the sociodemographic variables listed in Table 2 in the Methods section. The results from the full regression table can be seen in the Supplementary section in Table B. The relationship of the total carbon footprint with the LCCOs of being a vegan or vegetarian, not owning a car, driving an EV, buying renewable energy for the home, and no flights was negative meaning that, keeping all other variables constant, each of these options were associated with lower carbon footprints than among those who did not participate in these options. Heat pumps (in Iceland) and public transportation use (in Sweden and in Norway) showed a positive relationship with the total carbon footprint, but the coefficients were quite small and not significant. This means that having a heat pump or using public transportation in these countries could not predict the impact on the carbon footprint. The largest differences between those who participated in a LCCO and those that did not aligned with the bivariate analysis. Taking no flights and not owning a car resulted in the largest negative coefficients out of all the LCCOs, leading to carbon footprints that were 22 to 34% lower for those respondents who took no flights than those that did, and

28 to 39% lower for those that did not own a car. A regression model with all of the consumption options along with the control variables was also done for each country individually and resulted in similar coefficients for the LCCOs.

Looking at the control variables (Table 3), income, largely had the biggest impact of the control variables and showed that having a lower income correlated with having a lower carbon footprint as compared to those with high income. Household type generally had the next biggest impact, which showed that couples with child(ren) correlated with having a lower carbon footprint than single households. The degree of urbanity had the next largest impact, which showed lower carbon footprints in more urban areas than rural, however this lost its significance with vehicle ownership. Age, gender identity, and education level had minimal impacts and were more often insignificant than the other variables.

Lower income respondents compared to the higher income groups had a higher percentage of participants engaging with potentially cost-saving LCCOs such as having a vegan or vegetarian diet, not owning a car, and no flights. Couples with children and respondents from Norway were more likely to participate in LCCOs that require some financial investment like driving an EV or having a heat pump and those living in a single household were more likely to not own a car than other household types. As the level of urbanization increased, the level of engagement with having a heat pump or taking no fights decreased. Lower education levels were less likely to engage with all of the LCCOs except for no flights. Compared to other age groups more younger participants had a vegan or vegetarian diet and did not own a car. Participants from Sweden and Denmark engaged the most with having a vegan or vegetarian diet. Table F in the supplemental section shows the participation by each socio demographic group (as listed in Table 2) in each LCCO.

Table 3. Unstandardized beta from linear regression results of LCCOs. Significance: p<0.05^, p<0.01*, p<0.001**

		Consumption choice (as compared to those with no low-carbon consumption choice)		Income (as compared to high income)		Household type (as comapred to single household)			Degree of urbanization (as compared to rural)		Age (as compared to ages 55-80)		Gender (as compared to male)		Education level (as commpared to grad & post grad)			
		low-carbon consumption choice		low income	medium income	couple	single parent	couple w/ kid(s)	urban	semi urban	ages 15 to 40	ages 41 to 54	nonbinary/other	female	basic and secondary	college and vocational	(Constant)	Adjusted R2
Sweden	vegan/ vegetarian		-0.23**	-0.24**	-0.16**	0.01	-0.09**	-0.11**	-0.15**	-0.06^	0	0.02	0	-0.06*	0	-0.03	8.88	0.16
Finland			-0.17**	-0.34**	-0.14**	-0.03	-0.05^	-0.10**	-0.15**	-0.03	0.03	0.05^	-0.03	-0.06*	-0.01	0.05	9.16	0.16
Denmark			-0.28**	-0.35**	-0.18**	-0.02	-0.05	-0.1	-0.22*	0	-0.09	-0.08	0.01	0	-0.07	0.03	9.31	0.25
Iceland			-0.16**	-0.18**	-0.08*	-0.07	-0.06^	-0.15**	-0.04	0	-0.02	-0.03	-0.07*	-0.04	0.04	0.03	8.99	0.08
Norway			-0.13**	-0.17**	-0.16**	-0.01	-0.04	-0.15**	-0.14**	-0.05	-0.04	0.02	-0.04	-0.07*	0.05	0	8.94	0.11
Sweden	Renewable		-0.16**	-0.26**	-0.16**	0.01	-0.09**	-0.09**	-0.19**	-0.07^	-0.07*	-0.01	-0.01	-0.08**	-0.01	-0.03	8.97	0.13
Finland			-0.22**	-0.36**	-0.15**	-0.03	-0.05^	-0.07*	-0.17**	-0.03	0	0.03	-0.04	-0.06*	-0.03	0.04	9.27	0.18
Denmark			-0.11^	-0.34**	-0.19**	0	-0.03	-0.03	-0.23**	-0.01	-0.13^	-0.11	-0.02	-0.04	-0.07	0.05	9.31	0.18
Sweden	Heat pump		-0.04	-0.20**	-0.11*	-0.09^	-0.36*	-0.23**	-0.09^	-0.04	-0.05	0	0.07	-0.07^	0.08^	-0.01	8.93	0.1
Finland			-0.18**	-0.27**	-0.13**	-0.11*	-0.27*	-0.20**	-0.05	0	0.13	0.13**	-0.01	-0.06	0	0.08^	9.22	0.14
Denmark			-0.24**	-0.27**	-0.12	-0.25*	-0.41*	-0.48**	-0.1	-0.01	0.03	0.03	-0.07	-0.06	-0.11	0.09	9.52	0.23
Iceland			0.08	-0.16^	-0.01	-0.12	-0.32	-0.34*	0.06	0.04	0.1	0.08	-0.36	-0.08	0.11	-0.01	9.06	0.07
Norway			-0.11*	-0.14*	-0.10^	-0.13^	-0.13	-0.28**	0.04	-0.01	0.02	0.01	-0.13	-0.10*	0.13^	0.05	9.04	0.09
Sweden	No Flights		-0.33**	-0.23**	-0.14**	0	-0.09**	-0.09**	-0.22**	-0.08*	-0.09**	-0.01	-0.01	-0.09**	0.04	-0.02	9.27	0.21
Finland			-0.25**	-0.32**	-0.13**	-0.04	-0.07*	-0.10**	-0.21**	-0.05	0	0.03	-0.04	-0.07**	0	0.07*	9.47	0.2
Denmark			-0.42**	-0.29**	-0.12*	-0.02	-0.03	-0.08	-0.25**	0.01	-0.15**	-0.11^	0	-0.04	-0.01	0.09^	9.56	0.34
Iceland			-0.41**	-0.15**	-0.07^	-0.06	-0.04	-0.12**	-0.09*	-0.04	-0.07^	-0.04	-0.07*	-0.07*	0.07*	0.05^	9.23	0.22
Norway			-0.32**	-0.15**	-0.13**	-0.01	-0.04	-0.12**	-0.19**	-0.06^	-0.08*	0	-0.03	-0.09**	0.10**	0.03	9.15	0.18
Sweden	Public transportation		0.04	-0.25**	-0.15**	0.02	-0.09**	-0.08*	-0.19**	-0.07^	-0.08**	-0.02	-0.01	-0.08**	0.02	-0.03	8.86	0.11
Finland			-0.07*	-0.35**	-0.15**	-0.03	-0.06*	-0.08*	-0.14**	-0.03	0	0.03	-0.04	-0.07	-0.01	0.05^	9.18	0.14
Denmark			-0.06	-0.34**	-0.18**	-0.01	-0.03	-0.06	-0.20**	0	-0.12^	-0.11	-0.01	-0.03	-0.06	0.04	9.28	0.18
Iceland			-0.11**	-0.18**	-0.08*	-0.07^	-0.05	-0.14**	-0.03	0.01	-0.04	-0.04	-0.08*	-0.05	0.04	0.03	9.01	0.07
Norway			0.01	-0.18**	-0.17**	-0.01	-0.04	-0.14**	-0.15**	-0.05	-0.07^	0.01	-0.04	-0.08*	0.06^	0.01	8.93	0.09
		No car	EV	low income	medium income	couple	single parent	couple w/ kid(s)	Urban	semi urban	ages 15 to 40	ages 41 to 54	nonbinary/ other	female	basic and secondary	college and vocational	(Constant)	Adjusted R2
Sweden	Vehicle ownership	-0.33**	-0.23**	-0.21**	-0.14**	-0.07*	-0.26**	-0.20**	-0.08	-0.03	-0.03	0.01	0.02	-0.06*	0.01	-0.03	8.94	0.19
Finland		-0.40**	-0.14*	-0.24**	-0.11**	-0.14**	-0.22**	-0.26**	-0.04	-0.01	0.03	0.03	-0.04	-0.05*	0	0.04^	9.25	0.25
Denmark		-0.45**	-0.18*	-0.26**	-0.13	-0.26*	-0.37*	-0.43**	-0.03	0	0.07	0.07	0.11	-0.01	-0.03	0.08	9.43	0.29
Iceland		-0.50**	-0.16**	-0.16**	-0.08*	-0.13**	-0.18*	-0.24**	-0.01	0.02	-0.01	-0.02	-0.29*	-0.05	0.03	0.01	9.08	0.15
Norway		-0.35**	-0.19**	-0.16**	-0.14**	-0.05	-0.16^	-0.21**	-0.05	-0.03	0.01	0.03	-0.14	-0.06^	0.08^	0	8.99	0.17

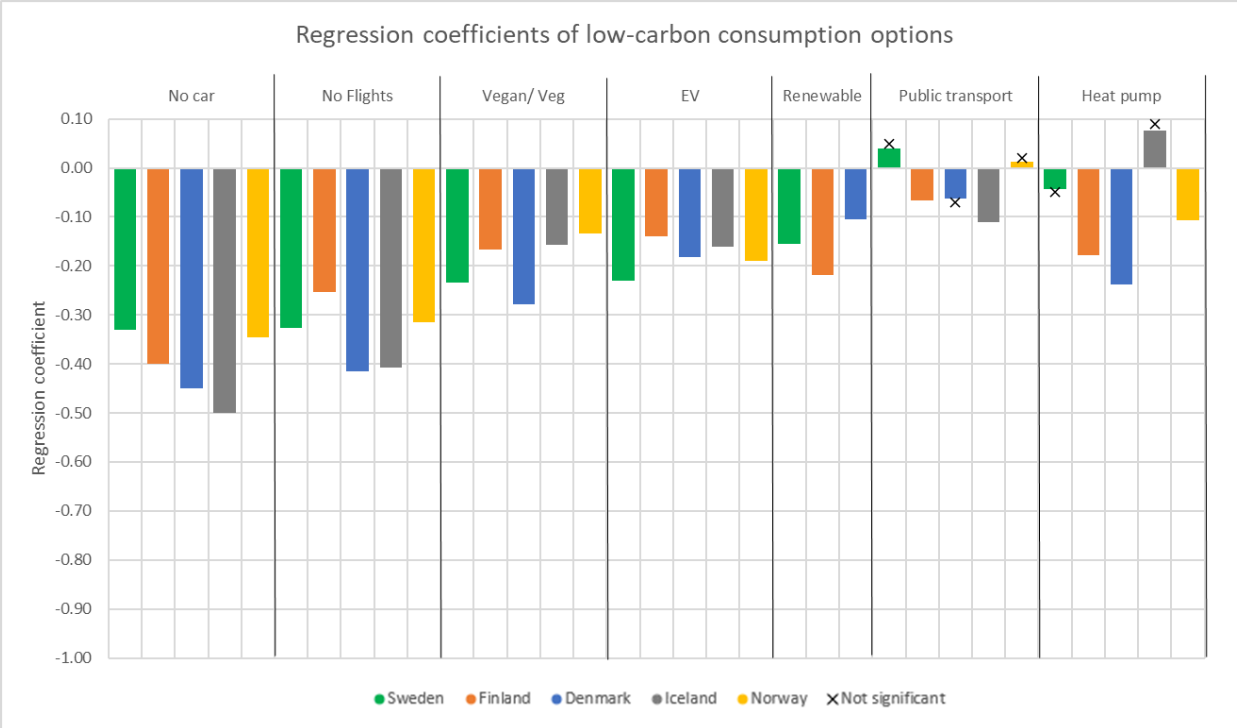

Figure 2. Regression coefficients of LCCOs for each country.

3.2 The impact of combining LCCOs

The total carbon footprints of study participants that adopted a combination of two of the LCCOs were also calculated (Figure 3). The combinations of having no car and not flying, being a vegan or vegetarian and having no car, and being a vegan or vegetarian and taking no flights led to the lowest average total footprints. The largest differences were seen in combinations that included no flights. Combinations with high participation rates included buying renewable energy for the home and taking no flights (34-54%), and using public transportation and taking no flights (12-42%). Combinations of LCCOs with being a vegan or vegetarian, driving an EV, or having a heat pump had some of the lowest ranges of participation.

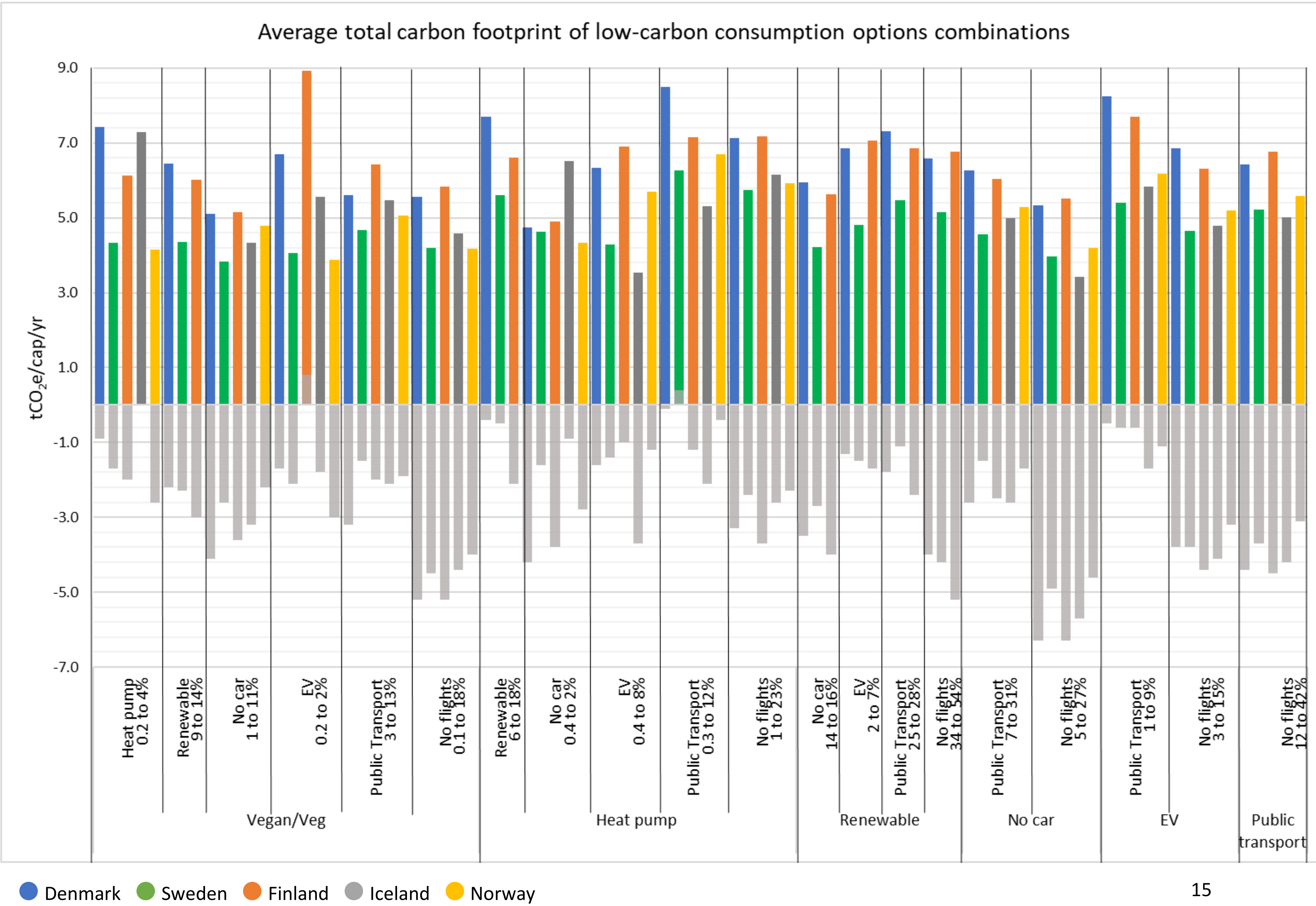
Average total carbon footprint of low-carbon consumption options combinations
tCO2e/cap/yr
9.0
7.0
5.0
3.0
1.0
-1.0
-3.0
-5.0
-7.0
Heat pump 0.2 to 4%
Renewable 9 to 14%
No car 1 to 11%
EV 0.2 to 2%
Public Transport 3 to 13%
No flights 0.1 to 18%
Renewable 6 to 18%
No car 0.4 to 2%
EV 0.4 to 8%
Public Transport 0.3 to 12%
No flights 1 to 23%
No car 14 to 16%
EV 2 to 7%
Public Transport 25 to 28%
No flights 34 to 54%
Public Transport 7 to 31%
No flights 5 to 27%
Public Transport 1 to 9%
No flights 3 to 15%
No flights 12 to 42%
Vegan/Veg
Heat pump
Renewable
No car
EV
Public transport
Denmark
Sweden
Finland
Iceland
Norway

Figure 3. The average carbon footprint per capita of a combination of two LCCOs in each Nordic country with the range of percentage of respondents who participated in each of the combinations of two of the low carbon consumption choices.

Each combination of two LCCOs was added to a linear regression model to see their relationship with the total carbon footprint with the control variables in Table 2. The results of all of these linear regression models can be seen in Table B in the supplementary section. Figure 4 shows the regression coefficients (unstandardized beta) for the LCCO combinations for each country. The combination of behaviors that had the largest negative coefficients was the same as those with the lowest absolute carbon footprints. Having no car and taking no flights led to footprints that were 50-61% lower than those who owned cars and took flights, whereas taking only one of these actions led to footprints that were only 26-34% lower. Having a vegan or vegetarian diet and taking no flights led to footprints that were 43-49% lower than those who did not choose these consumption options and compared to engaging in only one of these LCCOs footprints were only 26-34% lower. Having a vegan or vegetarian diet and not owning a car led to footprints that were 33-45% lower than those who did not choose both of these LCCOs, while participating in only one of these actions led to footprints that were only 25-30% lower. Not all of the combinations were significant in every country, and there were a few combinations with small—and generally insignificant—positive coefficients.

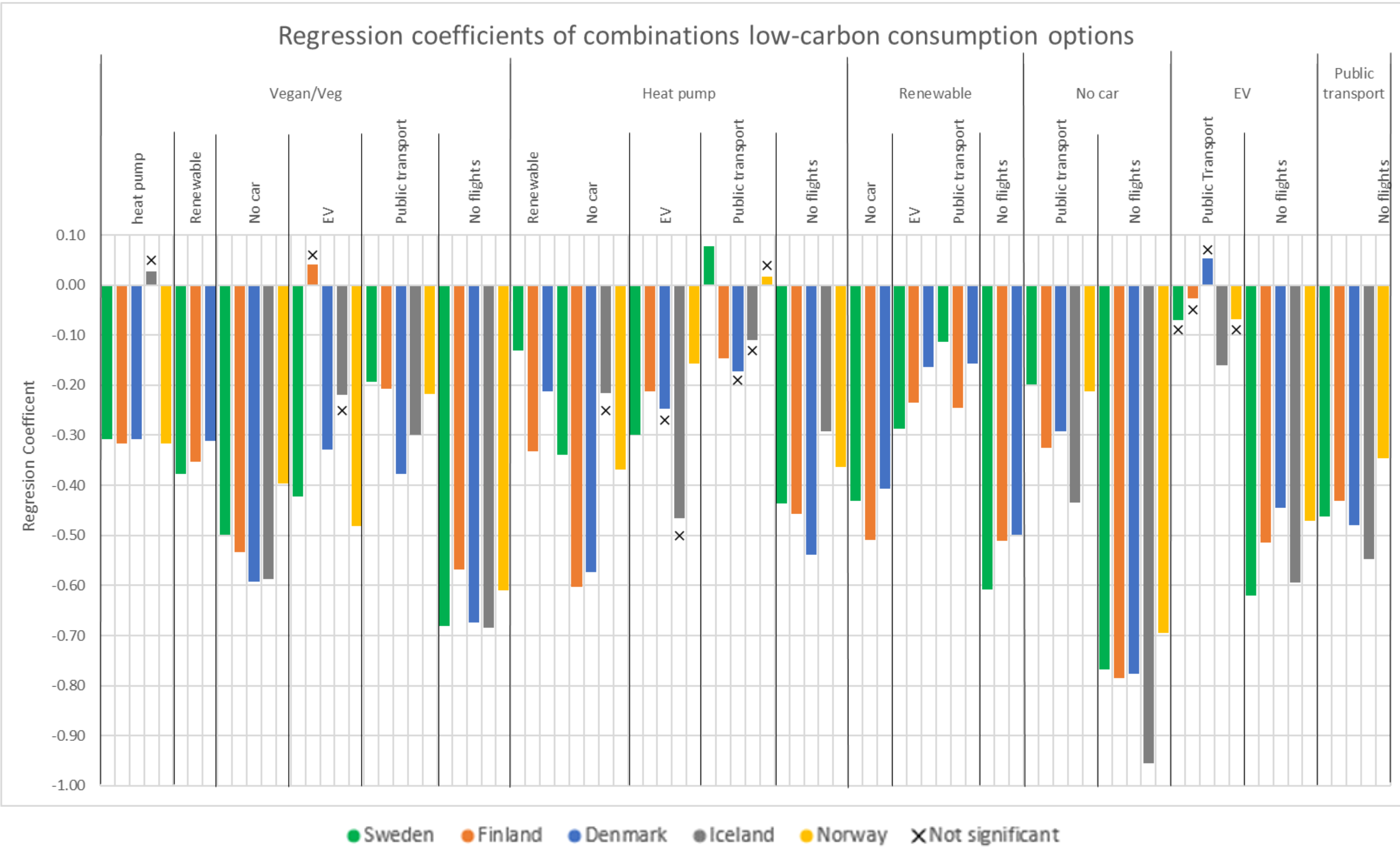

Figure 4. Regression coefficients of the combination of two LCCOs for each country.

Since respondents sometimes participated in more than one LCCO, the correlation of LCCOs was explored using Spearman Rank Correlation. All of the correlations were quite weak, but some of the more interesting results include significant and positive correlations between being a vegan or vegetarian and having no car (also with public transportation use), and being a vegan or vegetarian and buying renewable electricity for the home. A positive correlation means that if participants participated in one of these LCCO then they were more likely to participate in another LCCO. There was a negative correlation between having no car (also public transportation use) and taking no flights, which means that participants who did not own a car were more likely to take flights than car owners. Buying renewable electricity for the home and heat pumps both positively correlated with taking no flights. The correlation table can be seen in the Supplementary section in Table C.

4. Discussion

In this study, we aimed to see the difference in the total carbon footprints of respondents from a carbon footprint calculator survey who participated in LCCOs compared to those that did not. We also aimed to see if there were any rebound effects associated with participation in the LCCOs. The single LCCOs that lead to the lowest overall carbon footprints from participants were not owning a car (4.4 to 6.2 tCO_2e/cap/yr) and having a vegan or vegetarian diet (4.5 to 6.2 tCO_2e/cap/yr).

The article contributes to the understanding of the potential and conditions of lifestyle changes to reduce GHG emissions. Social scientists participating in the IPCC 6th Assessment Report have highlighted the importance of demand-side options to mitigating climate change (Creutzig et al., 2018), which have resulted in review studies (Ivanova et al., 2020; Creutzig et al., 2022a) and a new chapter in the report (Creutzig et al., 2022b). Our article adds to this knowledge by quantifying per capita emission reduction potential of key options. It does so in the context of affluent Nordic countries, including countries with decarbonized electricity provision, which further highlights the importance of the demand-side options in comparison to the supply-side. It also considers the impact of lifestyle options on the total carbon footprints per capita, taking into account rebound effects at household level. Compared to previous studies (Ivanova et al., 2020), our results highlight the very high reduction potential of car-free living (-2.1 to -3.0 tCO_2e/cap/yr), taking no flights (-2.1 to -3.5 tCO_2e/cap/yr), and having a vegan or vegetarian diet (-1.6 to -2.2 tCO_2e/cap/yr). Notably, the effect of having an EV is somewhat lower than in Ivanova et al. (2020), even in countries with a decarbonized grid, although still relatively high (-1.1 to -1.7 tCO_2e/cap/yr).

While our study highlights the high mitigation potential of low-carbon lifestyle options, it also shows the insufficient level of their adoption (besides avoiding air travel, whose adoption rate is inflated by Covid-19 travel restrictions) and the insufficient level of reductions resulting from adopting just one LCCO. The combinations of LCCOs that were associated with the highest difference in emissions were being a vegan or vegetarian and no flights along with not owning a car and no flights. However, even the most impactful combinations of two options do not bring emissions to the levels required for compatibility with 1.5-degree targets. Assuming a globally equal fair share of emissions per capita, Akenji et al. (2021) estimates the 1.5 degree-compatible per capita emissions at 2.5 tCO2e/cap/yr in 2030 and 0.7 tCO2e/cap/yr in 2050. The only combination of low-carbon lifestyle options that comes close to the 2030 threshold was found in Iceland for those respondents who did not own a car and did not take any flights (3.4 tCO2e/cap/yr). Reaching globally fair 1.5 degree-compatible targets in affluent Nordic countries not only requires a decarbonized electricity and adopting two very impactful low-carbon lifestyle options, but also farther reaching changes in the supply side (e.g. reduced carbon intensities of imported products, agriculture, etc.) and changing activity and spending patterns in other domains, beyond the most impactful ones.

Participating in a vegan or vegetarian diet led to the lowest average total footprints in Denmark (6.2 tCO_2e/cap/yr) and Norway (5.0 tCO_2e/cap/yr) and when controlling for socio-demographic variables in the regression this relationship was found to be significant. Participating in a vegan or vegetarian diet was weakly positively correlated with choosing other LCCOs (no car, public transportation use, renewable electricity) by our survey respondents. Having a vegan or vegetarian diet has been seen as an overall effective suggestion in Koide et al. (2021a) where dietary shifts showed consistent impact across all Japanese cities in the study, whereas the effects of changes in transportation and home energy varied. Respondents who had adopted a vegan or vegetarian diet did not have a rebound effect, which is similar to other studies (Ottelin et al., 2020). However, in other studies rebound effects have been seen with consumers switching to plant-based diets (Grabs, 2015, Bjelle et al., 2018, Sorrell et al., 2020). The Nordic countries tend to have Western diets which include a high level of consumption of animal products (Bruno et al., 2019), so there is potential for reduction.

Changes in transportation, such as living “car-free”, driving an EV, and using public transportation have shown to have some of the highest mitigation potentials of the low-carbon choices studied in the literature (Ivanova et al., 2020, Koide et al., 2021b, Bjelle et al., 2018). Similarly in this study, not owning a car was associated with some of the lowest overall total footprints (4.4 to 6.2 tCO_2e/cap/yr), and, along with not taking flights, was associated with some of the largest differences (-2 to -3 tCO_2e/cap/yr) between those who participated in a LCCO to those that did not. Also, as observed in other studies, there were rebound effects observed in not owning a car (Ottelin et al., 2017) and driving an EV (Bjelle et al., 2018). Not owning a car and using public transportation had a negative correlation with not flying. Ottelin et al. (2014) found in Finland a trade-off between not owning a car and air-travel, however Czepkiewicz et al. (2019) in a study of Reykjavík, Iceland did not find evidence of this trade off, which could be due to the high affluence of the area or the car-oriented culture found there. Not owning a car and taking no flights were both particularly impactful in Iceland in our study.

Not flying was the consumption option that had some of the highest mitigation potential (-2.1 to -3.5 tCO_2e/cap/yr), which was confirmed with linear regression. Many respondents did not engage in flying (55-89%), but the total carbon footprint of those who did not fly (5.4 to 7.5 tCO_2e/cap/yr) was not associated with lowest absolute footprints. The high participation rate in not taking flights is most likely due to the survey being conducted during the COVID-19 pandemic when there were various travel restrictions. The emissions found in the leisure travel domain, which includes emissions from air-travel, in this study are lower than before the pandemic for Iceland and Finland according to studies of their capital areas, which may have higher emissions than the country average (Czepkiewicz et al., 2019, Czepkiewicz et al., 2018).

Purchasing renewable electricity for the home has been found to be a mitigation option in the literature with high potential (Koide et al., 2021a, Koide et al., 2021b, Ivanova et al., 2020) and the mitigation potential found in our study was within the range found in the literature, but was not one of the top mitigation consumption options in our study, however it was one of the consumption options in this study that had a high participation rate (45-60%). Heat pumps were most effective in Denmark and Finland, which have the least decarbonized energy systems of the countries in our study and quite ineffective in Iceland, which has almost 100% renewable energy sources for home heating. Both of the home energy low-carbon energy choices (renewable electricity and heat pumps) positively correlated with no flights. Heat pumps were mostly found outside of the urban area and studies have found that emissions from traveling abroad are highest in the city center (Czepkiewicz et al., 2019).

Rebound effects from these low-carbon choices were small and mostly insignificant. The only significant, yet small, rebound was found in Sweden in participants who did not own cars. This could be due to the car free participants having higher emissions than car owners in the domains of housing energy, leisure travel, and, of course, public transportation. The trade-off between owning a car and leisure travel was discussed above and the higher housing emissions could be explained by more single people participating in not owning a car and not having the benefit of sharing emissions with others in their household, since the emissions from housing energy are divided by the number of people in the household. Other studies, as mentioned above, have found rebound effects from many of these LCCOs (Bjelle et al., 2018, Grabs, 2015, Sorrell et al., 2020). However, a similar study in Sweden which used transaction data and a lifestyle survey to calculate the carbon footprints to explore the potential emission reductions of the low-carbon choices of not flying, not owning a car, having a vegan diet, and not living in a detached house, also found a very limited rebound effect (Andersson and Nässén, 2023). Andersson and Nässén (2023) suggest that the limited rebound effect may be due to their sample having strong pro-environmental attitudes, so the participants may be motivated to reduce their carbon footprints and might have been engaging in multiple low-carbon options. Our sample could also be biased towards respondents who have stronger pro-environmental attitudes, which could explain the minimal rebound effect seen.

4.1 Policy recommendations

There are many different options and pathways for individuals to reduce their carbon footprints through their lifestyles. To support low carbon lifestyle changes, policies must consider the infrastructure, institutional, and behavioral lock-ins along with rebound potential (Ivanova et al., 2020). For the Nordic countries, this study highlights which of the selected LCCOs have the highest participation rates, the lowest overall carbon footprints, which options tend to correlate with other options, and which combinations of options leads to the most reduction potential, which could be leveraged by policy makers to construct policies that will have the most impact on GHG emission reduction from personal consumption. Dubois et al. (2019) suggests that policies should focus more on vehicles, air travel and diet rather than focusing mainly on energy saving options, which align with the consumption options with the most reduction potential in our study. Many of the Nordic countries in our study have highly decarbonized energy systems, so focusing on the domains of travel and diet are crucial.

The findings of the study provide a positive message to individuals, who aim to reduce their climate impact: it is possible to make a significant difference with one’s personal consumption choices. At the same time, the low participation in the studied activities reveals that governments cannot rely on voluntary lifestyle changes alone, but much more guidance, regulation, and infrastructure provision is needed. In particular, carbon pricing policies and other taxes should be extended from motor fuels and energy to flights and high intensity food products, such as meat and cheese, as well.

4.2 Limitations and future research directions

This study focused on seven different LCCOs within the carbon footprint domains of diet, transport, and home energy. The LCCOs were chosen for this study because of their high mitigation potential according to the literature. However, there are many other LCCOs that have significant mitigation potential that were not explored. Some examples of other LCCOs with reduction potential over 0.5 tCO_2/cap/yr found in the literature reviewed include: food waste reduction (Bjelle et al., 2018), home energy saving actions (Salo and Nissinen, 2017, Jones and Kammen, 2011), zero energy homes (Koide et al., 2021a, Jones and Kammen, 2011), decreasing annual income (Shigetomi et al., 2021), and taking multiple actions in the goods and services domain by buying less, repairing goods, renting or sharing goods, or buying products with environmental labels (Salo and Nissinen, 2017).

There are uncertainties and limitations with the data collection for the survey and the calculation methods used for the CBCFs in this study which are as listed in Heinonen et al. (2022). Particular to this study, in regards to calculating the mitigation potentials of certain low-carbon choices, it is difficult to isolate the impact of the LCCO. Even though we try to control for other factors that affect the total carbon footprint such as income, household, degree of urbanity and other sociodemographic variables through regression, there are other lifestyle components that we did not account for that may impact their overall carbon footprints. People with certain lifestyles may be inclined to choose the low-carbon choices selected for this study along with other consumption options or actions that reduce GHG emissions, which was observed in our data for behaviors like being a vegan or vegetarian and not owning a car, for example. It is difficult to pinpoint if the differences seen in the carbon footprints due to the low carbon consumption options are because of causation or correlation, so we cannot make any causal claims. To address this limitation, further research such as longitudinal studies could be designed to better identify the reduction potential of LCCOs and rebound effects.

The calculation of the emissions from these low-carbon choices is based on the information that was collected from the survey and the assumptions that were used to calculate the carbon footprints, which leads to some uncertainty. Looking at the LCCO of being a vegan or vegetarian, there is one value for the GHG emissions per year associated with both non-meat diet types. This could be improved upon for future studies. It is also unknown whether the food that the respondent is eating is sustainably produced, local, organic, or seasonal, which can have an impact on the emissions and mitigation potential (Ivanova et al., 2020, Koide et al., 2021a, Bjelle et al., 2018). When respondents chose that they purchased renewable energy for their home, it is unspecified what energy source their renewable electricity is coming from which impacts the GHG emissions (Cherubini et al., 2009). Individuals have little control over energy systems and infrastructure, so purchasing renewable electricity from an energy company will not necessarily have an immediate impact on production, but as an increase in demand on the market. The method of public transportation was also not asked (an average GHG coefficient was used) and the partial adoption of this behavior was included in the analysis, not a complete shift to this LCCO. The performance of a heat pump can vary with the model type and outdoor temperatures, both of which are not taken into account for our calculations. The emissions calculated for transportation related choices are also based on the assumptions listed in the methods section in Heinonen et al. (2022), but the calculation of the emissions from EVs has been improved since our previous study by adding the production and maintenance values to better reflect the lifetime emissions of owning a vehicle.

In order to transform consumption to be compatible with 1.5 degree warming, changes within the structures (political, economic, technical, and societal) that behavior is embedded in are necessary (Hirth et al., 2023). Further research, such as in depth interviews with the survey respondents, is needed to see what structures exist which are enabling their participation in these LCCOs as well as the barriers that exist to participating in LCCOs. This further insight could inform policies on how to best enable low-carbon consumption.

5. Conclusion

This study shows the potential of selected LCCOs and their impact on the total CBCFs of survey respondents from the Nordic region. Engaging in LCCOs was associated with lower CBCFs. Also, the limited rebound effects found are a promising indication that low-carbon lifestyles have the potential to avoid the negative indirect effects that have been found in previous research. The LCCOs that were associated with the lowest carbon footprints, not owning a car and being a vegan or vegetarian, and the largest difference in CBCF, no flights, should be taken into account when creating mitigation policies. Only one combination of the low-carbon choices in one country led to an average footprint low enough to be 1.5 degree warming compatible and the participation in this combination of choices was low. Higher adoption rates of multiple LCCOs are necessary to meet the vast reductions required to stay within the 1.5 degree limits.

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