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The spatial distribution of carbon footprints and engagement in pro-climate behaviors – Trends across urban-rural gradients in the nordics

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ABSTRACT

Climate change mitigation to the 1.5 °C calls for significant and extensive climate actions. Nordic countries are showing high engagement to climate change mitigation while the consumption and lifestyle-based carbon footprints are among the global highest. Majority of global greenhouse gas (GHG) emissions are connected to household consumption where various behavioral changes have been presented in order to reduce the personal carbon footprints. Previous research has shown how behaviors are connected to the living environment and urban structure, which have shown having an impact in forming variations in our lifestyles and behavioral patterns. In this study, with a survey dataset of ~8000 respondents across the five Nordic countries, the engagement of respondents to different climate and carbon mitigation actions were analyzed and linked to their calculated carbon footprints. Three types of behavioral clusters were found among the respondents, one presenting conscious pro-climate behavior, one relating to frugality behavior, and one cluster related to self-sufficient behavior. The pro-climate behavioral intentions were present more in urbanized areas together with high climate motivation, whereas frugality behavior was level across the urban gradient, and finally respondents from less urbanized areas emphasized self-sufficient behavior. The stated behavioral intentions of the respondents were in contrast to their carbon footprints. Carbon footprints related to leisure consumption were highest in the urban regions and everyday consumption related footprints in the rural regions. Interestingly, only frugality behavior was associated with lower carbon footprints both in everyday and leisure consumption categories, whereas climate conscious behavior was positively related to leisure consumption footprint but negatively related to everyday consumption. The findings emphasize the variation of lifestyles based on different actions in different urban forms where the engagement to climate change mitigation presents differently. The results underline the importance of understanding the role that the built environment plays in being linked to the behavioral patterns and the need to increase the knowledge of the climate impacts of behavioral choices.

1. Introduction

The latest IPCC results shows that we do have possibilities to mitigate climate change into the 1.5 °C requiring fast, direct, and extensive carbon emission mitigation actions (IPCC, 2021). Affluent and democratic countries tend to be more likely to engage in climate actions and have higher climate concern and perceived climate responsibility (Pohjolainen et al., 2021). However, when looking at the global emissions induced by these countries, or the consumption-based carbon footprints, the wealthier countries are causing the largest greenhouse gas (GHG) emissions (Hubacek et al., 2017; Ivanova et al., 2016). Democratic and wealthy Nordic countries are among the highest in average carbon footprints per capita (Clarke et al., 2017; Ivanova et al., 2016). Still, a recent study in Finland, for example, found people perceiving their lifestyles climate sustainable and requiring no significant change to mitigate climate change (Lehtonen et al., 2020).

When majority of the global GHG emissions are based on household consumption (Hertwich and Peters, 2009; Ivanova et al., 2016; Koide et al., 2021a), multiple studies have shown the potential of consumption and demand-side changes in climate change mitigation (Bjelle et al., 2021; Bjelle et al., 2018; Dietz et al., 2009; Moran et al., 2020; Vita et al., 2019; Wynes and Nicholas, 2017). To reduce the consumption-based

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carbon emissions, different ambitious lifestyle changes have been suggested in urban context (Koide et al., 2021a,b). In general, the highest domains for climate significant behaviors are transportation, food and housing including energy usage (Ivanova et al., 2020), where the carbon emission reduction potential of behavioral shifts has been quantified the highest mitigating impact being living car-free, avoiding air travel, switching to a plant-based diet, and switching to green energy (Tolppanen et al., 2021; Wynes and Nicholas, 2017). Downscaling consumption itself is also often suggested as a necessary mitigation action, but it may have rebound effects that offset some of the reductions (Sorrell et al., 2020). A recent study from Finland highlighted that even the downscaling of consumption to an assessed basic income level is insufficient to mitigate the consumption-based emissions to a climate-sustainable level if no other measures are taken (Kalaniemi et al., 2020). However, a combination of lifestyle changes, potentially combined with a reduction in consumption, might already allow climate-sustainable living even in the affluent Nordic countries (Heinonen et al., 2022b). It has also been suggested that a more local approach to pro-climate action suggestions is required according to the heterogeneity of lifestyles and urban structures (Koide et al., 2021a).

Consumption has shown to relate strongly to the behavioral and cultural context but also to the existing infrastructure and institutions (Coutard and Shove, 2019; Schrage and Kjærås, 2022; Warde, 2017; see also Creutzig et al., 2016b), and through them to the availability of opportunities for consumption and pastime (Heinonen et al., 2013a). To reach the decarbonization goals we need changes in both the built infrastructure and the infrastructure of our behavior, such as social norms, institutions, and routines (Creutzig et al., 2016b) which have been researched to be related to climate significant behaviors together with the perceptions of climate issues (Thøgersen et al., 2021). The urban structure and built environment are in relation to the residents' lifestyles and consumption habits, which plays a significant role in different emission sources (Heinonen et al., 2013a,b). Denser urban areas have been found to be connected to higher carbon emissions through urban consumption-oriented lifestyles (Heinonen and Junnila, 2011) and through more cosmopolitan lifestyles showing as elevated air travel activity (Czepkiewicz et al., 2018, 2020). The structural arrangements of cities have also an impact on the perceived climate impacts of our daily patterns (Schrage and Kjærås, 2022; see also Ewing and Cervero, 2010; Lamb et al., 2018). The trend shows in urban lifestyles, where for example the above-mentioned more carbon intense travel behaviors are more common among urban dwellers with higher pro-environmental attitudes (Árnadóttir et al., 2019).

Motivations for taking climate actions can be diverse, when worry about climate change and environment-related values can lead to more pro-climate actions (Bouman et al., 2020) but the high worry of climate issues doesn't necessarily implicate high behavioral engagement to climate friendly lifestyle changes (see Lehtonen et al., 2020). When explaining the prediction and change for the behaviors, the Theory of Planned Behavior (TPB) approaches the behavioral intentions which are driven by attitudes, subjective norm, and perceived behavioral control (Ajzen, 1991). Extending the TPB including personal moral obligation to act has shown significance engaging to climate change mitigation (Chen, 2016). In social change, the ABC (Attitude, Behavior, Choice) model representing attitudes driving behaviors individuals choose to adopt are argued not being enough to explain the complexity of human behavior and criticized for the ignorance of institutional and local context where the behaviors take place (Shove, 2010). As argued, the infrastructural arrangements should be noted as enabling and sustaining our social practices (Shove et al., 2015). For example, vehicle use depends on the built infrastructure and social norms (Thøgersen et al., 2021), and residential location affects the patterns of consumption and lifestyles (Heinonen et al., 2013a,b). The results have also shown the variation in actions and perceptions of climate change mitigation due to spatial and socioeconomic position (Weckroth and Ala-Mantila, 2022) which underlines the social diversity of climate change mitigation.

This calls for further research on the engagement to pro-climate behaviors in different urban scales to better understand the drivers of engagement to demand-side mitigation actions in different living environments. This article approaches this spatial engagement in pro-climate behaviors by looking at how engagement in different climate mitigation actions is distributed across the urban-rural gradient, and how the engagement is connected to the climate motivation and climate concern, and finally how these affect the consumption-based carbon footprints. The study focuses on the Nordic countries utilizing a survey with ~8000 participants about the carbon footprints, climate attitudes and engagement in pro-climate behaviors. While the public engagement in climate change mitigation has been previously researched (see Lorenzoni et al., 2007; Whitmarsh et al., 2011), this study for the first time includes the consumption-based carbon footprints together with information about engagement in pro-climate behaviors as indicators for lifestyle and actions climate impacts. This article approaches the effects of urban structure on behavioral and lifestyle choices to continue the approach of carbon emission reduction pathways on different urban scales (see Ottelin et al., 2019a). We will show that the pro-climate behaviors form distinct behavioral clusters dependent on the associated lifestyle choices relating to socioeconomic status, living environment, and expressed climate concern of the respondents. Likewise, we show that these lifestyle behaviors will affect different parts of the respondent's carbon footprint, depending on the consumption categories they most relate to.

2. Research design and the data

2.1. Research design

This research examines how different climate actions with their climate motivation and climate concern are being presented spatially in the Nordic countries together with the assessed consumption-based carbon footprints. The analysis presents how different climate actions are correlating and forming behavioral clusters, how the climate motivation and climate concern show in these clusters and how these clusters locate on urban scales. The assessed carbon footprints are analyzed as total footprints and as consumption behavior-based clusters to see how the variation of lifestyles shows spatially in footprints. The total footprints and lifestyle-footprints are analyzed as dependent variables on how climate behavior clusters, socioeconomic variables and urban scales explain the variation in carbon emissions and lifestyles. Fig. 1 presents the hypothesized relationships between the studied variables.

2.2. The data and the collection

The data consists of responses to a survey-based calculator (carbonfootprint.hi.is) of consumption-based carbon footprints of the residents of Nordic countries. The survey was tailored to each Nordic

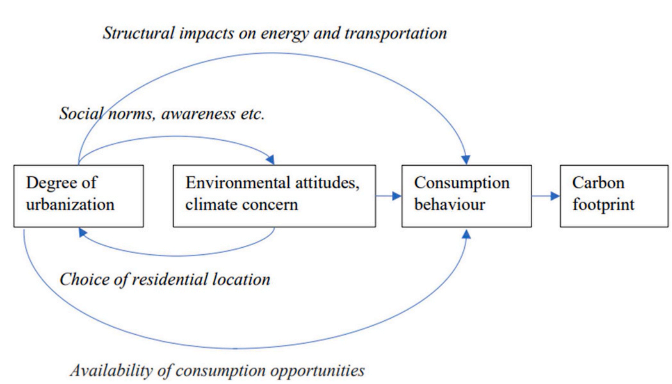

Fig. 1. Schematic diagram of the potential relationships between the studied variables.

country in terms of the footprint assessments, measured the consumption and lifestyle behaviors of the respondent and gave information about their climate attitudes, climate actions, and spatial location. Only people who participated in the housekeeping of their household were asked to fill in the survey, therefore eliminating for example children from the target group, but the respondents were asked for the household composition, and to report for the whole household. The calculators were equal to one another except for the GHG intensity values associated with consumption on different domains (see Section 2.2 for the footprint calculations), and salary levels in the background variables. The calculated footprints cover the personal consumption share and use a per capita assessment basis. Other sections of the survey covered climate attitudes, engagement in pro-climate behaviors and climate concern as the driver, and perceived well-being. A rich variety of background variables was also collected. The surveys were offered in all the main languages in each country. The calculations are presented in detail in an online methodology document at carbonfootprint.hi.is/methodology.

The data collection was conducted mainly through online marketing in Facebook during autumn 2021 and spring 2022, with the respondents encouraged to share their results and invite people in their social networks to participate, this leading to additional responses. The final collection includes 7682 full responses from all the Nordic countries, divided across the countries as shown in Table 1. The target was to reach a high number of high-quality responses with the only criterion being having a residency in one of the Nordic countries. The representativeness over the whole populations of the covered countries was not expected. The sociodemographic biases are acknowledged and discussed as well as the uncertainties related to how these should be recognized in interpreting the findings. Data and the collection are described in more detail in Heinonen et al. (2022b). The number of respondents, population density per km^2 according to Eurostat (2018b), response rate compared to total population and degree of urbanization according to Eurostat (2018a) per municipality are presented in Fig. 2. Number of respondents and total population per degree of urbanization (Eurostat, 2018a,b) and country are presented in Fig. 3. Iceland exhibited far higher participation rates compared to its total population and Denmark far lower. The participation along urban-rural gradient was ambiguous, with some countries experiencing higher urban and some higher rural response rates. In municipalities where total population was low, even a couple of participants could lead to a high response rate. However, as the aim of the study was not to present a representative sample of the population distribution in the studied countries, the representativeness of the data was deemed adequate.

2.3. *The consumption-based carbon footprint assessment*

The consumption-based carbon footprints were calculated using a hybrid model combining the traditional input-output analysis (IOA) with physical quantity data and process emissions (e.g. Suh, 2004), with the emphasis strongly on the latter component. The footprint calculations include eight domains: diet, housing energy, vehicle use, public transport use, long-distance travel, goods and services, pets, and summer cottages and second homes. Of these only the goods and services category is assessed with a pure IOA, which reduces the typical IO-based carbon footprint problems due to the inherent linearity and homogeneity assumptions (see e.g. Heinonen et al., 2020; Lenzen et al., 2010; Rodrigues et al., 2018; Temursho, 2017). The assessed footprints are the so-called personal carbon footprints which assign to an individual all emissions from their consumption regardless of where consumption or the emissions take place (Heinonen et al., 2022a). Major durable goods were excluded from the assessment. The IO part combines monetary spending reported by the respondents with the intensities per monetary unit from the Exiobase multi-region IO model (Stadler et al., 2018). The footprint calculations are explained in detail in Heinonen et al. (2022b).

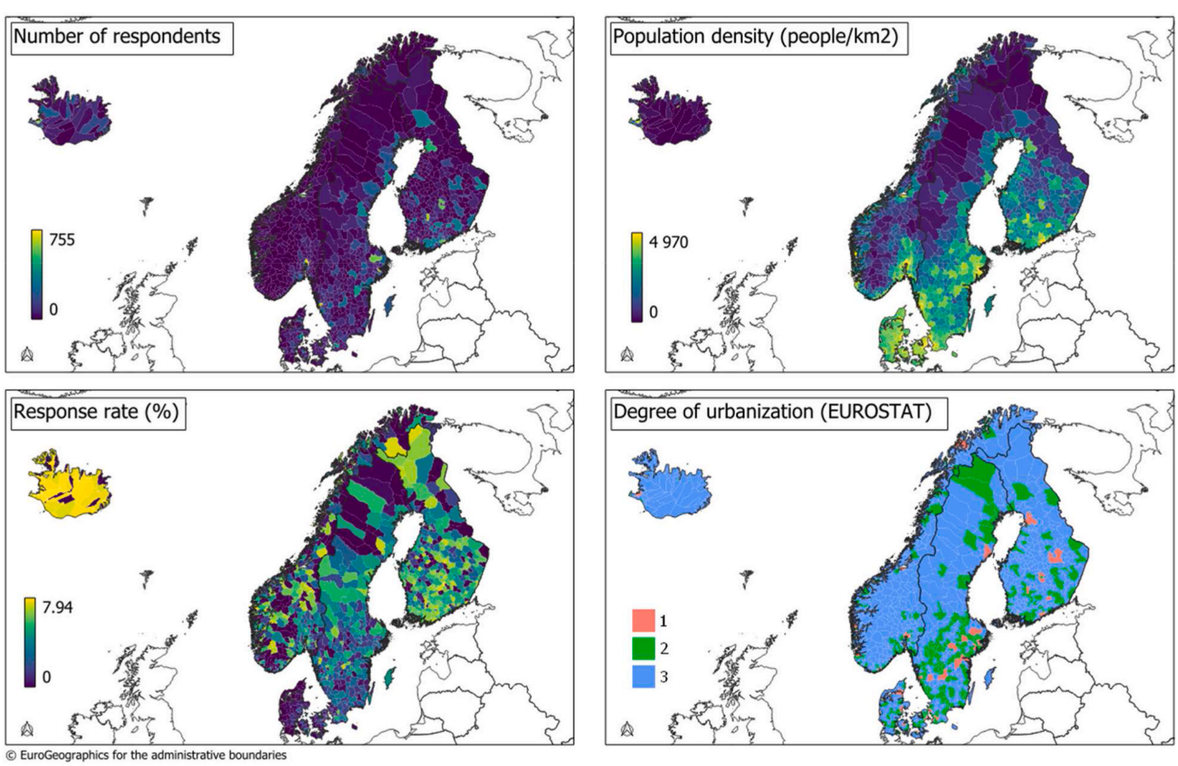

Fig. 2. Number of respondents, population density, response rate of total population and EUROSTAT based degree of urbanization (1 = cities, 2 = towns and suburbs, 3 = rural areas) per municipality in the studied Nordic countries (Eurostat, 2018a,b, 2020).

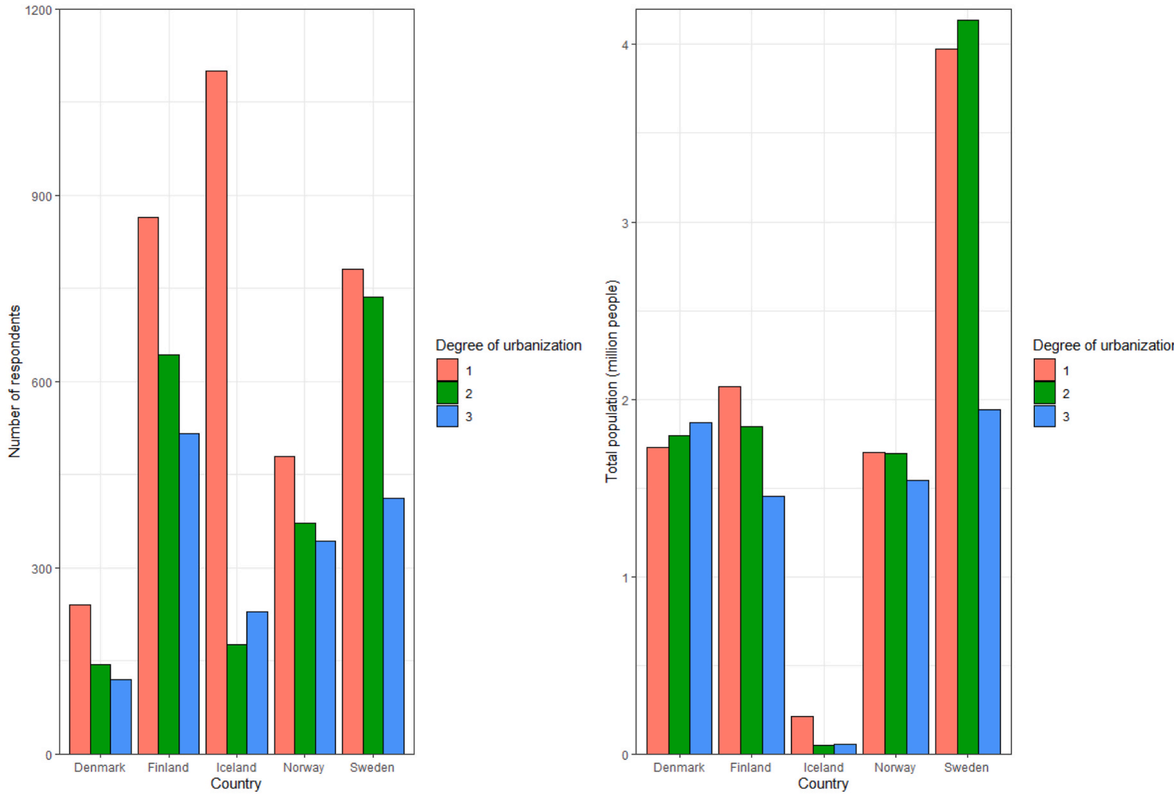

Fig. 3. Number of respondents and total population (in millions, 2018 estimate) per degree of urbanization (1 = cities, 2 = towns and suburbs, 3 = rural areas) and country (Eurostat, 2018a,b).

3. Analysis

3.1. Initial data processing

Full disclosure of the variables utilized in the data processing and analysis is given in Appendix A. The survey data was uploaded to RStudio program version 2022.07.1554 (R version 4.1.1.) where all analyses were conducted.

The respondents were asked about their climate attitudes and worries on a scale from 1 to 5 with the options 1) Not at all, 2) Slightly, 3) Moderately, 4) Very, 5) Extremely. Engagement in several pro-climate actions was also queried with a similar scale and with options 1) Not at all, 2) Very little, 3) Somewhat, 4) To a great extent, 5) Completely. If the respondent chose an option from 2 to 5, a continuation question "I do it to reduce my carbon footprint" was presented with the same answer options. If the respondent chose option 1 the continuation question was set to equal 1 as well. With the question about the intent to reduce driving (I avoid driving), those who had reported no vehicles in their possession and answered "yes" to the question "*I have deliberately chosen not to have a car*" were interpreted to correspond to the respondents who had strongly reduced their driving and hence their answer to the question about reduced driving was set to 5. This was because those respondents that had answered "yes" to the question were not presented with the question "*I avoid driving*". Likewise, their climate motivation to avoid driving was deduced from their climate motivation to not own a car in the first place. In addition, respondents were presented with a set of questions related to their overall expressed level of climate concern to gather how they perceived the threat possessed by it.

Socioeconomic background variables related to income, education level and household size of the respondents were collected to control their influence on the consumption-based carbon footprints as well as the size of their home (m^2). Prior to the analyses, education level of the respondents was aggregated as follows: degrees from basic to secondary or vocational level education were classified as class 1, undergraduate degree as class 2, and graduate and postgraduate degrees as class 3. The respondents were also asked to map the place of their residence on the presented interactive map as precisely as possible. To assign each respondent with a corresponding degree of urbanization according to their residential environment, Eurostat's assessment of urbanization for the year 2018 was utilized (Eurostat, 2018a) and individual observations assigned a degree of urbanization on a three-level classification from the most urbanized to the most rural according to the nearest classified location at their country of residence. Finally, the observations were subset based on whether individual respondents had correctly placed themselves within their country of residence by creating a 2 km wide buffer zone for each of the included countries according to Eurostat's 2020 Countries-dataset (Eurostat, 2020) and determining whether an observation was located inside this perimeter. As a result, with some respondents not having marked their residential locations correctly, a total of 7341 observations were subjected to further analysis.

3.2. Statistical analysis

Statistical analysis was conducted utilizing generalized least squares-factor analysis, standardized two-way analysis of variance (*ANOVA*) and robust mixed-effect linear regression. The statistical significance of individual terms was set at the level of $p < 0.05$ and significant loading of variables to an individual factor at value of 0.3 prior to the analyses.

3.2.1. Behavioral pattern analysis

To study how different pro-climate actions converged together, a factor analysis with the R package *psych* was run for the variables *I avoid meat, I avoid food waste, I reduce housing energy consumption, I avoid driving, I avoid flying, I purchase services instead of products, I buy second-hand, I avoid buying things, I maximize lifetime of products, I practice gardening, I practice gathering, I practice fishing, I practice hunting* and *I* *practice bindiving*. Based on the theoretical framework presented in Section 1 and our research design presented in Section 2.1. We hypothesized that the pro-climate actions would form three distinct behavioral clusters, relating to the climate consciousness, frugality and self-sufficiency of the respondents. To test this prediction, a generalized least squares-factor analysis based on a polychoric correlation matrix was run with oblique promax-rotation, allowing the formed factors to correlate with one another due to a likely high cross-cutting correlations between different pro-climate actions.

Pro-climate action sum-scores were constructed according to individual pro-climate behavior factors and their correlation to sum-scores of corresponding climate motivation-factors evaluated with Pearson's correlation coefficient to estimate the underlying climate motivation behind the actions. Furthermore, an independent corresponding factor analysis was run for the climate concern-related variables *Climate change worry, Harm to future generations, Personal harm, Personal importance, Influence on others, Voluntary lifestyle change, Importance of mitigation, Lifestyle sustainability* and *Knowledge of impacts* and the resulting factor sum-scores again compared to pro-climate behavior factor sum scores with Pearson's correlation coefficients to estimate how general climate concern was related to the formed pro-climate behavior factors. The pro-climate behavior and climate concern factor sum-scores were compared between different urbanization zones and countries with the standardized two-way analysis of variance (*ANOVA*) to study their distributions across the urban gradient.

3.2.2. Carbon footprint analysis

To understand how urban form and self-expressed climate actions affected the corresponding portions of carbon footprints, linear mixed-effect models were fitted to the data. As the carbon footprint data was characterized by strong outliers in all categories which were likely to skew standard mixed-effect regression results heavily, a robust estimation approach with the R package *robustlmm* was adopted instead. Robust linear models determine so-called robustness weights based on robust estimation equations and resulting bounded functions, which are then utilized on residual and random effect regression terms to down-weight outliers in the model estimation. The resulting model is thus able to better estimate the average impact individual parameters or the grouping structure have on the model fit at the cost of increased residual error at the sampled extreme values. For further information, see Koller (2016).

The dependent variables utilized in the models were respondents' carbon footprints related to leisure consumption behavior (***Carbon footprint of leisure consumption*** = *Carbon footprint of long-distance travel* + *Carbon footprint of goods and services* + *Carbon footprint of pet ownership* + *Carbon footprint of summer cabin ownership*), everyday living consumption behavior (***Carbon footprint of everyday living*** = *Carbon footprint of diet* + *Carbon footprint of housing* + *Carbon footprint of personal vehicles* + *Carbon footprint of public transportation*) and their combination, total consumption (***Total carbon footprint*** = *Carbon footprint of leisure consumption* + *Carbon footprint of everyday living*). The dependent variables were log-transformed before being utilized in the analysis to achieve better model fit. The independent variables utilized included respondent's income according to country-wise income deciles (*Household income decile*, ordinal), education level (*Education level*, dummy), size of their housing unit (*Housing size*, continuous), number of people in the household (*Household size*, continuous), degree of urbanization (*Degree of urbanization*, dummy) as well as the factor sum-scores for climate behaviors (*climate conscious behavior*, *frugality behavior* and *self_suff_act*, continuous). Nationality of the respondent (*Nationality*, nominal) was utilized as the mixed random effect variable to account for differences in e.g., urban form, energy production system and mobility between the studied countries, potentially resulting in substantial differences in the related carbon footprints. Goodness-of-fit of the models was estimated utilizing the pseudo R^2-values calculation methodology proposed by Nakagawa and Schielzeth (2013). To evaluate whether an individual parameter had a meaningful impact on the model fit, Satterthwaite-approximated degrees of freedom for a corresponding standard mixed-effect model along with the *t*-values of the constructed robust mixed-effect model were utilized to evaluate approximate *p*-values for the robust model terms, according to Luke (2017).

4. Results

4.1. Climate concern and pro-climate behaviors

Based on the factor analysis, the action variables formed three types of behavioral clusters presented as *climate conscious behavior, frugality behavior* and *self-sufficient behavior*. Likewise, the climate concern-related variables converged into three different factors, of which the first one was determined to reflect the overall climate concern of an individual respondent the best and was named as *climate concern*. The actions determining the resulting factors were converted into related sum-scores, which distribution across the urban gradient and countries are presented in Fig. 2. Factor loadings are presented in Tables 2 and 3.

The variables converged to underlying factors generally as expected, with *I avoid meat, I avoid driving, I avoid flying, I purchase services instead of products*, *I buy second-hand* and *I practice bindiving* forming the climate conscious behavior factor, *I avoid food waste, I reduce housing energy consumption, I avoid flying, I avoid buying things* and *I maximize lifetime of products* forming the frugality behavior factor and *I practice gardening, I practice gathering, I practice fishing* and *I practice hunting* forming the self-sufficient behavior factor. As *I avoid flying* had virtually identical loadings for both *climate conscious behavior*- and *frugality behavior*-factors it was determined to belong to both. As *I practice bindiving* did not have its related climate motivation determined in the survey, it was temporarily dropped from *climate conscious behavior* sum-scores in the following correlation analysis.

The sum-scores of climate motivation of actions correlated most significantly with the sum-scores of climate conscious behavior ($r = 0.790$, $p < 0.001$***) including actions to reduce eating meat, reduce driving, avoid flying, prefer services to products and prefer buying second-hand. The sum-scores of climate conscious behavior correlated also strongest with the sum-scores of climate concern-factor ($r = 0.616$, $p < 0.001$***). The correlation of climate motivation to actions was weaker with frugality behavior ($r = 0.610$, $p < 0.001$***) and they were also less related to the overall climate concern-factor sum-scores of the respondents ($r = 0.458$, $p < 0.001$***). The self-sufficient actions were not measured together with their climate motivation in the survey but had clearly the weakest relation to overall climate concern-factor ($r = -0.006$, $p > 0.05$).

In more urbanized areas, climate concern is presented higher than less urbanized areas (Fig. 2). According to results of two-way ANOVA, degree of urbanization was more important in determining the distribution of climate concern than nationality of the respondent (Table 3). Climate conscious and frugality behavior sum-scores were more strongly determined by the nationality of the respondent than urban gradient but both variables had nevertheless significant impact. In urbanized areas climate conscious behavior scores were higher, whereas frugality behavior shows constant high trend through all the countries and urbanization zones, only presenting small variation in the more rural

Table 1
Number of full responses from each country.

Sweden	2032
Finland	2134
Norway	1333
Denmark	516
Iceland	1667
Total	7682

Table 2
Factor loadings of the studied climate action variables. The factors were renamed as follows: 1) climate conscious behavior 2) frugality behavior 3) self-sufficient behavior. Variables determined to belong in the underlying factor have been bolded.

Variable	Climate conscious behavior	Frugality behavior	Self-sufficient behavior
I avoid meat	**0.81**	−0.07	−0.24
I avoid food waste	0.05	**0.55**	0.10
I reduce housing energy consumption	0.09	**0.51**	0.10
I avoid driving	**0.45**	0.22	−0.25
I avoid flying	**0.34**	**0.31**	0.01
I purchase services instead of products	**0.38**	0.12	−0.01
I buy second-hand	**0.47**	0.16	0.10
I avoid buying things	0.04	**0.76**	−0.06
I maximize lifetime of products	−0.12	**0.82**	0.01
I practice gardening	0.17	−0.01	**0.67**
I practice gathering	**0.39**	−0.19	**0.71**
I practice fishing	−0.29	0.04	**0.76**
I practice hunting	−0.40	0.12	**0.75**
I practice bindiving	**0.44**	−0.08	0.24

Table 3
Factor loadings of the studied climate concern-variables. Factor 1 was selected as the best reflection of the overall climate concern of the respondents. Variables determined to belong in the underlying factor have been bolded.

Variable	Loading (Factor 1)	Loading (Factor 2)	Loading (Factor 3)
Climate change worry	**0.93**	−0.03	0.06
Harm to future generations	**1.01**	−0.11	−0.02
Personal harm	**0.76**	0.05	0.06
Personal importance	**0.80**	0.11	0.10
Influence on others	0.22	**0.58**	0.09
Voluntary lifestyle change	−0.10	**0.78**	−0.09
Importance of mitigation	**0.86**	0.17	−0.04
Lifestyle sustainability	−0.18	0.08	**0.65**
Knowledge of impacts	0.15	−0.08	**0.76**

regions of Sweden, Iceland, and Finland. Self-sufficiency score was clearly dependent on the urban gradient, exhibiting the highest relative difference of all studied factors between F-values for *Degree of urbanization* and *Nationality* (Fig. 4, Table 4).

4.2. Carbon footprints

Personal carbon footprints show the variations in different urbanization levels, when everyday consumption related carbon footprints are lowest in the most urbanized areas, whereas footprints related to leisure consumption are highest in the urbanized areas and lower in more rural areas (Fig. 5, Table 5). These variations on emission sources on different urban scales are defined here as everyday footprints and leisure footprints presenting different lifestyle and consumption patterns in different living environments. Overall trend shows slightly lower total footprints for respondents living in most urban areas compared to more rural respondents (Fig. 6, Table 5).

The results of the robust linear mixed regression by the studied sector of the carbon footprint are presented in Table 6. *Estimate*-column denominates the impact of a single parameter on the log-transformed dependent variable compared to the geometric sample mean reflected by the *Intercept*-term. *t*-values along with *p*-values reflecting the effect size and approximate significance of a model parameter signal whether an individual variable was significant in explaining the variation observed in the corresponding sector of the carbon footprint. Pseudo R^2-values presented at the bottom of the table represent the total proportion of observed variance explained by the model within an individual sector of the consumption-based carbon footprint, accounting for both marginal R^2 signifying the variance explained by fixed effects and conditional R^2 signifying the variance explained by both fixed and random effects. The proportion variance explained by the random effect nationality of the respondent (*Nationality*) is also included in the latter portion of the table as its own column (determined as conditional R^2 - marginal R^2). As *I avoid flying* was included in both *climate conscious behavior*- and *frugality*-factor sum-scores, it was included in the analysis as its own variable and omitted from these sum-scores in the regression analysis to prevent including it in the model twice.

To explain the variation in carbon footprints, income, education, housing unit size, household size and urbanization level were analyzed together with the climate conscious, frugality and self-sufficient behavior factor sum scores. The conditional pseudo R^2-values were 0.418 for the total consumption-based carbon footprint, 0.471 for the everyday consumption behavior related footprint and 0.214 for the leisure consumption behavior related footprint, respectively. All the footprint sectors were negatively related to frugality behavior whereas, interestingly, climate conscious behavior was positively related to leisure consumption footprint and negatively related to everyday consumption and total footprint. Self-sufficient behavior seemed to be associated with higher carbon footprints across all of the studied consumption sectors. Of the control variables, higher income and housing unit size were positively associated with high carbon footprints across all of the studied consumption sectors, whereas number of people in the household exhibited an opposite, negative trend. The impact of higher degree of urbanization and education were ambiguous, both associated with higher leisure consumption but lower everyday consumption behavior related footprints. The resulting impact on total carbon footprints was slightly positive for higher degree of urbanization compared to more rural areas and insignificant for education.

The impact of the mixed random effect, nationality, was most strongly associated with the everyday consumption behavior related carbon footprints where it explained 19.8% of the associated variance. On the contrary, the impact was weakest in the leisure consumption behavior related carbon footprints where the random effect explained only 6.7% of the observed variance. For the total carbon footprints, the impact of the random effect was 17.7%, reflecting more so the high variance associated with everyday consumption behavior related carbon footprints compared to the lower international differences in the leisure consumption behavior related carbon footprints.

In addition, sensitivity analysis was performed for pro-climate behavior factor sum-scores, and *I avoid flying* by excluding them from the model to test how much of the associated variance was attributable to correlation with control variables included in the model. The resulting marginal and conditional pseudo R^2-values along with their proportional change compared to the full model values are presented below in Table 7. According to the results the limited models were far worse in predicting the corresponding carbon footprints, indicating that pro-climate behaviors impacted these significantly, with far lower pseudo R^2-values for both fixed effects and complete models.

5. Discussion

This study shows the spatial engagement to climate mitigation in different urban scales on how climate actions, climate motivation and climate concern are showing in urban structures and how these are related in carbon footprints. The analysis shows how climate mitigation actions are forming behavioral clusters located differently in urban structures with the climate motivation, climate concern and assessed consumption-based carbon footprints. The results show variation in lifestyle-based behaviors in different urban levels in Nordic countries, where the climate conscious behaviors were more present in more urbanized areas connected to the higher climate concern and climate

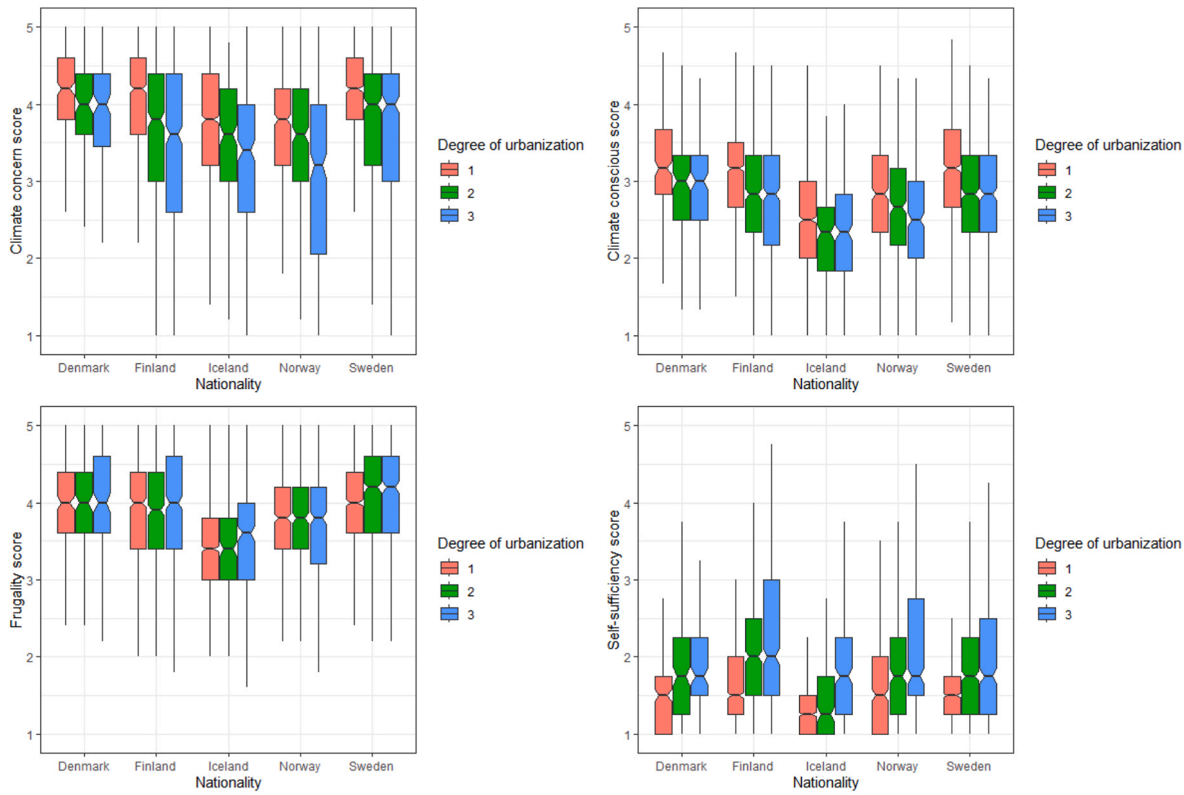

Fig. 4. Factor sum scores of the climate concern, climate conscious actions, frugality actions and self-sufficiency actions of the respondents by country and degree of urbanization (1 = cities, 2 = towns and suburbs, 3 = rural areas). Median values per group are marked by notches and black horizontal lines.

Table 4
Results of a standardized two-way ANOVA per climate concern and pro-climate behavior factor sum-scores. Strongest impact on individual dependent variables of the studied grouping variables (Degree of urbanization, Nationality and interaction term, Degree of urbanization:Nationality) has been highlighted in the table.

Variable	Degree of urbanization		Nationality		Degree of urbanization: Nationality	
	F-value	*p*	*F-value*	*p*	*F-value*	*p*
Climate concern	***245.97***	***<0.001****	*57.3*	*<0.001****	*0.74*	*>0.05*
Climate conscious behavior	*101.010*	*<0.001****	***171.329***	***<0.001****	*1.913*	*>0.05*
Frugality behavior	*47.567*	*<0.001****	***144.585***	***<0.001****	*0.721*	*>0.05*
Self-sufficient behavior	***527.133***	***<0.001****	*76.063*	*<0.001****	*2.642*	*<0.05**

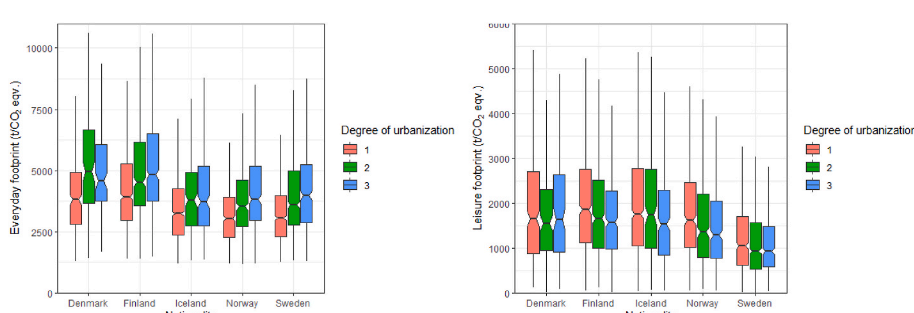

Fig. 5. Everyday consumption behavior and leisure consumption behavior-related carbon footprints of the respondents by country and degree of urbanization (1 = cities, 2 = towns and suburbs, 3 = rural areas). Median values per group are marked by notches and black horizontal lines.

motivation of actions. These present together in line with the higher socioeconomic position through higher education and income groups. Still, the leisure consumption behavior related carbon footprints are also the highest in the urbanized areas indicating higher urban consumption, as suggested previously by for example Heinonen and Junnila (2011), regardless of the indicated climate consciousness and high climate motivations. Here urban residents may have reduced their consumption according to the climate consciousness but not even near to a climate-sustainable level. More urban residents being aware of climate significant behaviors but might not acknowledge the significance of the overall consumption in their footprints, or not willing to sacrifice in some consumption domains when reducing the consumption in others which might interestingly reflect the negative spillover effect (e.g., Nilsson et al., 2017; Thøgersen and Crompton, 2009; Truelove et al.,

Table 5
Results of a standardized two-way ANOVA per carbon footprint-category. Strongest impact on individual dependent variables of the studied grouping variables (Degree of urbanization, Nationality and interaction term, Degree of urbanization:Nationality) has been highlighted in the table.

Variable	Degree of urbanization		Nationality		Degree of urbanization:Nationality	
	F-value	*p*	*F-value*	*p*	*F-value*	*p*
Carbon footprint of leisure consumption	***17.609***	***<0.001****	*14.983*	*<0.001****	*1.642*	*>0.05*
Carbon footprint of everyday living	***203.474***	***<0.001****	*51.689*	*<0.001****	*3.204*	*<0.05**
Total carbon footprint	*4.525*	*<0.05**	***13.179***	***<0.001****	*2.688*	*<0.05**

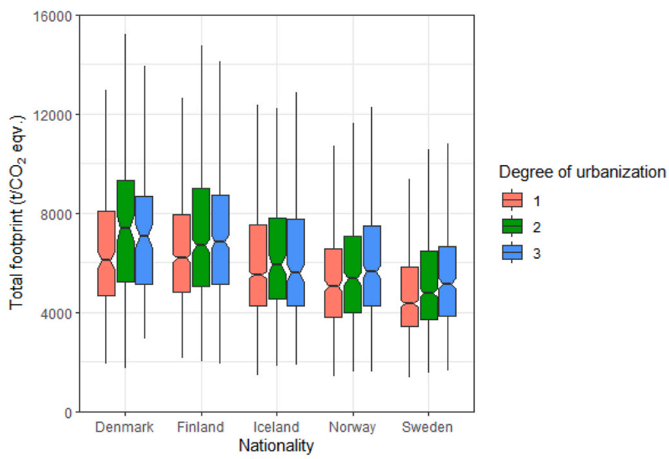

Fig. 6. Total consumption-based carbon footprints of the respondents by country and degree of urbanization (1 = cities, 2 = towns and suburbs, 3 = rural areas). Median values per group are marked by notches and black horizontal lines.

2014).

Results of the robust linear mixed effect regression analysis show that surprisingly only the frugality behavior was associated with both lower everyday and leisure consumption related footprints. On the contrary, the climate conscious behavior was associated with a lower carbon footprint only on everyday consumption but higher in the leisure consumption category. The self-sufficient behavior was associated with higher carbon footprint in both studied categories. Avoidance of flying was observed to result in lower carbon footprints across all consumption categories. Both everyday and leisure consumption related footprints grew with income and housing size and decreased with larger household size. The role of other control variables was more ambiguous. Higher education and urbanization levels led to higher leisure consumption but lower everyday consumption footprints. The role of income as well as household size have been identified as significant factors in explaining overall consumption-based carbon footprints (e.g. Ottelin et al., 2018; Salo et al., 2021) and the differences in consumption-based carbon footprints urban and rural areas have previously been recognized (e.g. Ottelin et al., 2019b; Miehe et al., 2016; Minx et al., 2013). Everyday footprints negative relation to conscious behaviors can be explained by everyday footprints presenting higher in less urbanized areas where actions like favoring low-emission housing or driving less are invalid to local lifestyles through infrastructure available. Possibly due to contextual enablers, i.e. the availability and proximity, residents in less urban areas seem to spend their growing income in more everyday commodities for example by consuming higher amounts of housing (measured as m^2 per resident) or transport by private vehicles (measured as km per year) and thus associated energy, as suggested by the monocentric city model (e.g. Brueckner, 2011; Dieleman et al., 2002; Wienderhofen et al., 2013). Similarly, urban residents seem to benefit from the compact and versatile built environment by having lower everyday footprints due to smaller apartment sizes, energy-efficient housing and availability of public transportation, for example. The leisure consumption related footprints exhibited an opposite trend in relation to urbanization, with urban residents

Table 7
Marginal and conditional pseudo R^2-values along with the proportional change of the factor sum-score limited models compared to the full models.

Model	Mar. R^2	Con. R^2	Change mar. R^2 (p.)	Change con. R^2 (p.)
Carbon footprint of leisure consumption	*0.075*	*0.159*	*−0.490*	*−0.257*
Carbon footprint of everyday living	*0.169*	*0.312*	*−0.381*	*−0.338*
Total carbon footprint	*0.135*	*0.296*	*−0.440*	*−0.292*

Table 6
Results of the robust linear mixed regression by different sections of the carbon footprint (leisure, everyday and total consumption). The pseudo R^2-values at the bottom represent the goodness-of-fit of the model, accounting for both marginal (fixed effects) and conditional (fixed + random effects) variance explained. Total proportion of variance explained by the random effect (nationality) is accounted for in the Nationality-column. Dummy-variables that belong to the same underlying parent-variable are grouped together with the color coding of the rows.

Fixed effects	Carbon footprint of leisure consumption			Carbon footprint of everyday living			Total carbon footprint		
Variable	*Estimate*	*t-value*	*p*	*Estimate*	*t-value*	*p*	*Estimate*	*t-value*	*p*
(Intercept)	7.701	63.44	<0.001***	8.839	80.30	<0.001***	9.203	89.80	<0.001***
Household income decile	0.047	14.03	<0.001***	0.014	8.83	<0.001***	0.025	13.55	<0.001***
Climate conscious behavior	0.117	7.09	<0.01**	−0.229	−28.44	<0.001***	−0.164	−14.14	<0.001***
Frugality behavior	−0.183	−11.60	<0.001***	−0.296	−3.86	<0.001***	−0.069	−8.77	<0.001***
Self-sufficient behavior	0.078	6.14	<0.001***	0.050	8.05	<0.001***	0.055	8.75	<0.001***
I avoid flying	−0.132	−16.74	<0.001***	−0.014	−3.75	<0.001***	−0.059	−14.96	<0.001***
Education level_2¤	0.111	4.58	<0.001***	−0.038	−3.20	<0.01**	−0.001	−0.11	>0.05
Education level_3¤	0.177	7.42	<0.001***	−0.056	−4.85	<0.001***	0.012	1.04	>0.05
Housing size	0.001	4.83	<0.001***	0.002	20.40	<0.001***	0.001	17.92	<0.001***
Household size	−0.018	−2.25	<0.05*	−0.073	−18.60	<0.001***	−0.065	−16.20	<0.001***
Degree of urbanization_2 ¤	−0.080	−3.45	<0.01**	0.070	6.19	<0.001***	0.024	2.08	<0.05*
Degree of urbanization_3 ¤	−0.107	−4.15	<0.001***	0.092	7.33	<0.001***	0.030	2.35	<0.05*
Pseudo R2	*Mar. R^2*	*Con. R^2*	*Nationality*	*Mar. R^2*	*Con. R^2*	*Nationality*	*Mar. R^2*	*Con. R^2*	*Nationality*
	0.147	*0.214*	*0.067*	*0.273*	*0.471*	*0.198*	*0.241*	*0.418*	*0.177*

¤=Dummy variable

presenting higher values than their rural counterparts. This can in part be explained by the same differences in living environment, where urban development presents the residents with higher disposable income after their everyday consumption requirements have been met, resulting in carbon footprint rebound effects (e.g. Underwood and Fremstad, 2018; Ottelin et al., 2014).

Interestingly, the most significant impact of the behavioral clusters on leisure carbon footprint was observed for the frugality behavior cluster, which perhaps more so reflected pragmatic, economic incentives for the reduced consumption. Frugal behavior had a lower correlation with the climate motivation behind the actions than the climate conscious behavior cluster, which had higher influence in lowering everyday consumption related footprints. It would therefore seem that economic incentives related to everyday frugality are more effective in controlling one's leisure consumption related behavior compared to pure climate incentives. As the high climate conscious behavior scores were more common among the urban residents, who also had higher leisure consumption related footprints on average, it would seem that there exists some discrepancy between the values and actions of consumers in this regard also recognized as the concept of *value-action* or *attitude-behavior-gap* (e.g., Blake, 1999; Kollmuss and Agyeman, 2002). Whether this relates mainly to the attitudes, subjective norms or perceived behavioral control of the respondents or something else entirely is up to debate (e.g., Chen, 2016; Sutton and Tobin, 2011). The relationship was inverted for everyday consumption related footprint, where most negative influence was attributed to climate conscious behavior instead of frugality behavior. As urban residents were more likely to express higher climate concern and participation rate in individual climate conscious actions, the result could be interpreted as reflectance of the passive emission reduction benefits associated with the urban form and related infrastructure.

In addition, some everyday and leisure consumption behavior related actions may be guided by different social norms in the urban and rural environment, resulting in divergence of the related carbon footprints. Avoidance of flying having identical loadings for frugality and consciousness behavior clusters might indicate variance in motivators when these clusters diverged according to the urban gradient. For example, avoidance of meat in the diet may be more common and socially acceptable in urban rather than rural environments and among respondents of higher socioeconomic status (Deliens et al., 2022; Li et al., 2016; Linville et al., 2022) and the higher socioeconomic status related expectations may also increase the consumption of some goods and services as well as flight travel in more urbanized regions (Czepkiewicz et al., 2018; Yin and Shi, 2021). Social normativity and infrastructural arrangements have shown to favor certain types of traveling behaviors (see Árnadóttir et al., 2019; Thøgersen et al., 2021) which can either enable or hinder behavioral social change. These social norms and expectations could then reflect to the related sectors of consumption-based carbon footprints, as the results of the regression analysis in Table 5 seem to indicate.

The findings are in line with previous literature where different lifestyles and consumption patterns occur in different urban and built environments (see Heinonen et al., 2013a,b). Similarly, the urban infrastructure can provide conditions for demand-side patterns, for example in mobility and energy use through building design (see Creutzig et al., 2016a,b; Schrage and Kjærås, 2022). The results support findings from Weckroth and Ala-Mantila (2022) where the climate perceptions and climate actions show differently due spatial and socioeconomic positions in European level. Here the nationality of the respondent most strongly affects their everyday footprints which is most likely due to structural, society-level differences in household energy production and local mobility. On the contrary, nationality of the respondent played a far smaller role in the leisure footprints, which seems to be more related to the individual consumption choices and habits rather than society-wide larger trends.

Albeit the everyday consumption related footprints were higher among the rural respondents, it should be noted that the daily activities of rural residents may sequester carbon by their very nature, resulting in lower net emissions attributable to the individual. For example, private forest ownership rates are often higher with rural residents and their motives for forest management may include carbon sequestration among other things (e.g. Häyrinen et al., 2015; Urquhart and Courtney, 2011). Accounting for this "carbon handprint" impact along with the more commonly quantified footprint could further our understanding of the effect urbanization has on individual carbon budgets and provide new perspectives towards a sustainable, regenerative residential environment (Camrass, 2022; Heinonen and Ottelin, 2021). Holistic considerations of both structural and behavioral mechanisms guiding the individual consumption as well as the role and scalability of different residential systems in providing differentiating, beneficial environmental impacts are crucial in achieving this.

The limitations of this study are the potential biases in the data. The survey was answered individually but the analysis utilized the income and consumption of the household (per capita). Personal pro-attitudes and behaviors might not be equivalent with the high consumption of the household as there may be variation of lifestyles inside households. The survey being marketed via commercial social media channels leads to biases in sampling which hinders the national level representativeness (see Heinonen et al., 2022b for more details). There may be over-representation of people who are concerned of climate change and interested in their own carbon footprint. The data collection was placed during Covid-19 which might have affected people's normative consumption practices, like traveling behaviors, and limit the options available which might show in the carbon footprint assessment. In the assessments, there are also potential biases and skewness due the IOA method using average units, when for example the relation between affluence and quality of purchases does not show in the footprints, meaning that the footprints of the more affluent might be somewhat overestimated (see Girod and de Haan, 2010). Moreover, consciously choosing environmentally better, or low-carbon, products and services does not necessarily show as reduced emissions. This, however, affects only the IO part of the footprints, meaning 20–30% of the overall footprint. At the same time, the calculations covering the rest 70–80% include many improvements in comparison to pure IOAs in terms of reductions to the linearity and homogeneity assumptions and the aggregation error (Heinonen et al., 2022b). There might, however, also be spatial variation in the products within countries in the same broad product category, and in the emissions profiles of them. Such differences would go unnoticed in our assessment, which only covers country-level emission profiles. Finally, in the regression models, the explanation rates can be interpreted as relatively low, while in social and behavioral sciences this is often recognized as a general result through the complexity of social behaviors when different explanations might underlie through different combinations of variables.

In addition, some study design related uncertainties should be considered. It should be noted that since the estimation of urbanization was derived from a comprehensive yet coarse classification, some of the observed trends in the regression analysis may be attributable to fine-scale variation in urban gradient not captured by the study setting rather than wholly to the independent variable in question. For example, people with higher degree of education tend to exhibit higher income levels and inhabit central urban areas (e.g., Delmelle, 2016; Gennaioli et al., 2013; Glaeser and Resseger, 2010; Newbold and Brown, 2015) and as such the explanation power of education in estimating the carbon footprints may be inflated by this unquantified variance in income levels and urban density. Furthermore, as the different consumption-based carbon footprint sectors were roughly divided into leisure and everyday consumption related categories, some aggregation error is likely introduced in the results. For example, the consumption of goods and services was assigned to the leisure consumption category, although some of the associated consumption is inevitably more so related to everyday consumption behavior. It is also precisely the leisure consumption component where the Covid-19 crisis had the strongest impact. In addition, very likely urban living changed more during the Covid restrictions than rural living, for example the international travel restrictions affecting much more strongly the more mobile urban population (see e.g., Czepkiewicz et al., 2018 for details about why urbanites tend to travel more internationally). However, the main conclusions drawn from the models fit the study's theoretical framework well and can be made with fair confidence.

For future research, more knowledge of perceived social normativity of climate change mitigation and pro-climate behaviors should be included into the analysis to provide a stronger indicator for the behavioral intention and perceived behavioral control. To recognize more the influence of the built and living environment, the climate sustainability perceptions of living environments should be researched in order to show how infrastructural living conditions might enable or hinder pro-climate behaviors. This would lead to increasing the understanding of the behavioral engagement to climate change mitigation and create more climate sustainable pathways supported by urban planning.

From the policy perspective, the findings of the study highlight that local characteristics need to be taken into account in climate strategies and actions. Different approaches to enhance sustainable lifestyles are needed in urban and rural areas, since the awareness of climate change and the preferred sustainable consumption habits differ. However, the findings also suggest that information campaigns and other methods to increase climate consciousness are unlikely to be enough in changing consumer behavior. Despite the high climate concern, individuals' carbon footprint can be high. Thus, more binding regulation will be needed not only to enhance sustainable lifestyles but also to phase-out the most harmful consumption habits.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.clrc.2023.100139.

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