



Drivers of household consumption expenditure and carbon footprints in Finland

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ABSTRACT

Household consumption patterns contribute to climate change. Therefore, an understanding of the drivers of household consumption (food, housing, travel, services, and tangibles) and the related carbon footprint is crucial for policy design. This article studies household expenditure and carbon footprint in an affluent European country, Finland, using Household Budget Survey data from 2016 and an environmentally extended input-output model for Finland. The multivariate regression analysis includes demographic, socio-economic and spatial explanatory variables. Compared with previous literature in this field of research, the main contribution regarding variable selection is the inclusion of region and urban form interactions. The results show that the selection of spatial variables in the model affects the results and policy-relevant conclusions on the role of region, urban form, and their interactions as spatial drivers of expenditure and carbon footprints. Regarding the socio-economic characteristics, the study includes occupational status and shows that it has some effect on expenditure patterns even when the impact of education is controlled for. Another novelty of the article is to explore the decoupling of expenditure and carbon footprint from consumption-based perspective. Expenditure and carbon footprint are first analysed separately to address their drivers individually. Then, decoupling is examined by comparing the results of the drivers of expenditure and the carbon footprint. The analysis shows little evidence of the occurrence of absolute decoupling. The article discusses how analysis based on input-output data can show shifts in consumption patterns in terms of commodity groups but not on a product level. In all, the findings on the selection of spatial variables and decoupling, and related policy implications, contribute to the discussion on how to analyse household consumption and carbon footprints.

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1. Introduction

Current patterns of household consumption pose a challenge for climate change mitigation. Globally, the share of household consumption in global greenhouse gas (GHG) emissions has been reported as 72% in one estimate (Hertwich and Peters, 2009) and 65% in another (Ivanova et al., 2016).

Scholars (e.g., Hoekstra and Wiedmann, 2014) have highlighted the prevailing emphasis on improving the efficiency of production and supply rather than to addressing problems related to consumption patterns, i.e., the volume of consumption and type of

products purchased. There are doubts that efficiency improvements alone would be sufficient to solve environmental problems stemming from consumption, for instance, due to the required scale of emission efficiency improvements (Bjørn et al., 2018), and lacking evidence for the efficiency and composition of consumption to tackle effect of growing consumption (Rosa and Dietz, 2012).

Although the carbon intensity of energy supply plays an important role (Kerkhof et al., 2009), studies on Iceland (Clarke et al., 2017) and Norway (Steen-Olsen et al., 2016) show that current household consumption patterns result in high consumption-based GHG emissions even in a country with a low-carbon energy system. That said, the advantage and importance of the consumption-based approach is that it takes into account embedded emissions of imported goods (Peters and Hertwich, 2008) and overseas relocation of polluting industries, i.e., carbon leakage (Kanemoto et al., 2014). The approach should be addressed

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in policy (Barrett et al., 2013) as the emissions of imported goods remain a challenge while territorial emissions decrease as shown in a Swedish study (Schmidt et al., 2019).

Demand-side solutions (Creutzig et al., 2018) and the carbon footprint (CF) from household consumption have attracted growing attention in the literature such as analysis of household CFs in Flanders, Belgium (Christis et al., 2019) and four European regions (Ivanova et al., 2018). Understanding the drivers of household consumption expenditure and the related CF is crucial for policy development, and this study contributes to this field.

According to Hoekstra and van den Bergh (2002), changes in the CF can be decomposed into 1) a technology effect, i.e., a shift in the carbon intensity of production or a change in production technology, 2) a level effect, i.e., a change in total demand, as each euro spent has a carbon intensity above zero, and 3) a product-mix effect, i.e., a shift in demand as the carbon intensity of commodity groups varies. This study focuses on consumption patterns and therefore addresses level and product-mix effects.

The existing body of literature using survey-based data on household consumption expenditure has shown the main drivers of the CF (e.g., Druckman and Jackson, 2016). In most studies, income is identified as the most important predictor of households' CF, while Minx et al. (2013) show that income is not necessarily more important than other socio-economic characteristics. Additionally, Vita et al. (2020) find that higher income is not associated with a larger footprint in a study on participants of environmental initiatives. In addition to income and socio-economic characteristics, other factors may influence consumption patterns. For instance, the role of attitudes has been studied, but the results suggest that environmental attitudes are weak predictors of CF compared to income (Moser and Kleinhüchelkotten, 2018), and circumstances (Nässén et al., 2015). Also, Csutora (2012) showed how even pro-environmental behaviour had little effect on overall ecological footprints.

Several studies explore the effect of spatial variables on households' CF: Ala-Mantila et al. (2014) and Heinonen et al. (2013) in Finland, Fremstad et al. (2018) and Jones and Kammen (2014) in the United States, Gill and Moeller (2018) in Germany, Poom and Ahas (2016) in Estonia, and Wiedenhofer et al. (2017) and Zhang et al. (2016) in China. Further, a review article by Wiedenhofer et al. (2018) concludes that while findings often highlight the potential of dense urban areas to decrease direct carbon emissions, the indirect impacts may increase due to affluence and available consumption opportunities. Nevertheless, evidence on the role of place of residence is mixed (Ivanova et al., 2017). Ottelin et al. (2019a) propose that this inconsistency may result from different contextual factors in countries and cities.

The role of urban/rural typology of location as a driver of consumption and households' CFs is relevant for policy. Hence, research could contribute to knowledge of how different types of areas are correlated with the CF and which key elements facilitate low-carbon living. Additionally, the long lifespan and large investments associated with the urban form are important: buildings and transport infrastructures have effects that reach far into the future (Creutzig et al., 2016a), and the urban form shapes the opportunity space in which everyday life is arranged (Creutzig et al., 2016b).

To allow for policy-relevant outcomes, analyses of spatial characteristics need to be sufficiently detailed (Minx et al., 2013). For instance, classifications based on number of inhabitants in a municipality in Germany (Gill and Moeller, 2018) and population density of local administrative units across Europe (Ottelin et al., 2019b), and the NUTS (Nomenclature of Territorial Units for Statistics, as used in the European Union) classifications (Ivanova et al., 2017) provide interesting overviews of differences. Nevertheless,

the listed studies lack sufficient detail to inform area-specific policy-making and planning. Furthermore, Wilting et al. (2020) show that subnational differences in the household consumption CF are mainly derived from differences in final demand and call for regional policies to address these differences. The analysis in this study uses the area type (five urban/rural classes), geographical location, and their interaction to reveal differences among areas that may remain hidden if only the NUTS 2 or area type is used. The scale is essential because the characteristics of everyday living environments vary, e.g., within each NUTS 2 region.

Decoupling of economic output from its environmental impact (the technology effect) has been suggested to decrease environmental burdens. Overall, when the consumption-based approach is used to assess the decoupling of countries' economic output and CF, a tighter coupling of the two is observed compared to production-based approach (e.g., Cohen et al., 2018). Similar argument is also presented by Simas et al. (2017). There is some evidence of an absolute decoupling of the consumption-based CF from economic output over limited periods from the UK (Druckman and Jackson, 2009) and Sweden (Palm et al., 2019), but scholars remain cautious about the prospects for a similar long-term development.

While the decoupling literature in general focuses on aggregated macro-level (countries), the approach could also be useful for the study of detailed micro-level (household) consumption patterns, i.e., the coupling of expenditure and the CF. Previously, Isaksen and Narbel (2017) have studied the carbon intensity of consumption among income groups and found that the carbon footprint grows proportionally with income. See also (Serino, 2017). Exploring patterns in the relationship between expenditure and the CF is interesting, especially in terms of the product-mix effect. In Finland, the analysis of national accounts shows a relative decoupling of household expenditure and the CF (with the environmental impact growing more slowly than the economy over time) in 2000–2016 (Savolainen et al., 2019a). While national accounts can show aggregated consumption patterns, household-level data with information on household characteristics could be used to study this decoupling in more detail.

To examine the drivers of household consumption patterns, the latest (data from the year 2016) Household Budget Survey dataset on Finnish household consumption is used. It includes rich detail on the demographic, socio-economic, and spatial characteristics of households. Salo et al. (2019) show some descriptive results from the data but do not statistically analyse the apparent differences and explanatory factors.

This article makes empirical and modelling contributions to the literature on the household consumption CF. A high-resolution model is used to analyse households' expenditure patterns and CF separately and then compare the results. First, focus is on expenditure, i.e., the underlying phenomenon defining the volume and composition of consumption patterns. As CF calculations use aggregated emissions coefficients, this adds some uncertainty compared to the expenditure analysis. Therefore, it is beneficial to first analyse the expenditure data to understand the composition and drivers of consumption. Second, detailed household characteristics, such as occupational status in addition to often used explaining variable education, are incorporated into the model to add to previous empirical findings on the drivers of households' CF reported in studies from Finland (e.g., Ala-Mantila et al., 2016) and other countries. Third, the study makes a modelling contribution in showing how the model choice, especially regarding the spatial characteristics, affects the results. Fourth, modelling both expenditure and the CF from survey data and comparing the findings also provides a novel way to study decoupling in more detail than that provided by studies using economy-wide data. Overall, the contributions rely on and highlight the potential of and the need for

detailed data on household characteristics and expenditure patterns in modelling, thus the novel research approach and answering the research questions 2–4 have relevance beyond Finland.

1.1. Four research questions guide the analyses

- 1) What are the key demographic and socio-economic drivers of Finnish household expenditure in total and by consumption category?
- 2) How does consideration of region and the urban/rural typology enrich the understanding of the spatial drivers of consumption?
- 3) How do differences in consumption patterns affect the carbon footprint?
- 4) Do the expenditure and carbon footprint patterns show signs of decoupling?

The remainder of the article is structured as follows. Section 2 describes the data and introduces the research methods. Section 3 presents the results. Section 4 discusses the modelling, empirical, and policy implications and concludes the article.

2. Data and methods

2.1. Expenditure data of Finnish households

The household consumption expenditure data utilised in this study are from the Finnish Household Budget Survey (HBS), which was collected by Statistics Finland in 2016. Altogether, 3,673 households responded to the survey. The survey results were weighted to represent the total household population (2.7 million households with 5.3 million individuals) (Statistics Finland, 2018).

The expenditure data are classified according to the national version of the Classification of Individual Consumption by Purpose – Household Budget Survey (COICOP-HBS). The most detailed level includes 640 commodities (7-digit level). COICOP-HBS is harmonized with Eurostat's eCOICOP-HBS classification at the 4-digit level (Statistics Finland, 2018, appendix 3). The dataset also includes extensive information on the demographic, socio-economic, and spatial characteristics of each household.

In this article, households are the primary unit of analysis because they are the unit of primary data collection. However, the analysis takes into account the effect of the number of persons in the household. Within a household, the use of shared resources such as the dwelling, cars or durables as well as synchronised everyday activities are related to patterns of consumption and daily activities. Additionally, the life phase of individuals within the household likely influences the activities of all other household members.

Some modifications were made to the original HBS data. First, 147 households from the NUTS 2 region Åland were excluded. Åland, a group of islands, differs from the mainland of Finland in terms of administration, economy, language, and culture. Furthermore, there is a limited number of observational units in Åland in urban area classes. Second, households without any food expenditure (the 1st percentile) were excluded (36 households). This choice was made to reduce bias due to possible mistakes or outliers in the dataset. In other words, it is assumed that all households must purchase some food, but they do not necessarily need to consume anything else. After the exclusions (183 households), the number of observations was 3,490. The expenditure data (640 commodities) were aggregated into six thematic categories: total expenditure, food, housing, travel, services, and tangibles (descriptive statistics in Table 1).

2.2. Carbon footprint data

In this article, the CF refers to life-cycle-wide consumption-based GHG emissions. The analysis is limited to household consumption expenditure (see Heinonen et al., 2020 for definitions of consumption-based CFs). A common way of analysing the CF of household consumption is to use HBS data combined with GHG emissions intensities as previously done in several countries including Finland (e.g., Ala-Mantila et al., 2014), Norway (Steen-Olsen et al., 2016), Germany (Gill and Moeller, 2018), and Philippines (Seriño, 2017). Environmentally extended input-output (EEIO) models are widely used in estimating consumption-based emissions intensities (e.g., Tukker and Jansen, 2006). The models have been also used to estimate impacts and prioritise consumption-based policy measures to mitigate GHG emissions (Wood et al., 2017), and model scenarios of lifestyle changes (Vita et al., 2019).

The GHG intensity coefficients for commodities (kg CO₂eq/€) were estimated for this study and they are the most recent ones (calibration year 2015) available for Finland (Savolainen et al., 2019b). The estimation was carried out using the EEIO model ENVIMAT (Seppälä et al., 2011). The intensity coefficients were adjusted to the year 2016 with commodity-specific price indices. The ENVIMAT model is detailed, with 148 industries and 229 products, which ensures high precision in estimating the CFs. Since ENVIMAT is not a multi-region input-output (MRIO) model, the imported embodied emissions from the “rest of the world” were included using Life Cycle Assessment (LCA) inventory data. The GHG coefficients of imports from 2010 were adjusted by price indices to 2016. In the model, the GHG emissions of imported and domestic products were differentiated in terms of both intermediate and final use (e.g., household consumption).

The HBS expenditure data were aggregated to match the GHG intensity estimates in the ENVIMAT model. The expenditures were multiplied by the corresponding intensities, resulting in the CFs of 65 commodities for each household. The CFs were further aggregated into the same six thematic categories as in the expenditure dataset: total (65 commodities), food (15 commodities), housing (11 commodities), travel (13 commodities), services (10 commodities), and tangibles (16 commodities). Descriptive statistics of the CFs¹ are in Table 1.

In contrast to some previous studies analysing direct and indirect household emissions separately (e.g., Ala-Mantila et al., 2014), this article presents CFs that include both direct and indirect (i.e., embodied) GHG emissions. Embodied emissions are emissions from the production of commodities, whereas direct emissions include emissions from fuels and lubricants for vehicles and heating fuels. This methodological choice was made due to the decision to examine expenditures by thematic category.

2.3. Multivariate regression model

To examine the determinants of household consumption expenditure and related CFs, the following multivariate regression models were formulated:

¹ Due to the COICOP aggregation level, some of the 65 mentioned commodities include both tangibles and services, separable only at the detailed 7-digit level. In these cases, the expenditure data of services and tangibles were aggregated and categorised depending on the larger expenditure share (services or tangibles) to match the GHG intensities. Because of this mapping problem between the more-detailed expenditure data and less-detailed GHG intensities, the minimum expenditure in tangibles is zero euros, but the related minimum carbon footprint is 14.68 kg CO₂eq.

Table 1

Descriptive statistics. Figures are per household per year.

Variable	Definition and unit	Min	Max	Mean	Sd
Total	Total expenditure (excluding items outside consumption expenditure, e.g., tax-like charges and membership fees), €	4,568.06	295,402.38	39,489.24	24,578.11
Food	Food and non-alcoholic beverages, €	28.92	32,273.54	4,848.09	2,907.37
Housing	Housing, water, electricity, gas and other fuels, €	0.00	44,896.51	12,163.55	5,816.67
Travel	Transport and package holidays (incl. international travel), €	0.00	227,460.00	7,219.82	11,471.90
Services	All other services (e.g., education, health care, culture, recreation, restaurants)	84.00	112,040.80	6,880.63	6,089.60
Tangibles	All other tangible goods (e.g., clothing and footwear, furnishings, durables for recreation and culture), €	0.00	121,963.32	6,420.81	6,173.58
CF total	Total carbon footprint, kg CO ₂ eq	2,444.48	103,877.67	19,148.79	10,655.71
CF food	CF of food expenditure, kg CO ₂ eq	12.94	20,442.29	3,689.54	2,202.00
CF housing	CF of housing expenditure, kg CO ₂ eq	0.00	27,016.22	6,101.88	3,018.14
CF travel	CF of travel expenditure, kg CO ₂ eq	0.00	48,877.53	5,574.75	6,100.33
CF services	CF of services expenditure, kg CO ₂ eq	5.98	21,894.04	1,055.24	1,310.87
CF tangibles	CF of tangibles expenditure, kg CO ₂ eq	14.68	41,398.17	2,563.73	2,485.08
Income	Money income (household gross income less imputed income items), k€	-2.47	518.60	43.12	28.82
Debt	Total household debt, k€	0.00	1033.32	42.95	76.80
Number of cars	Number of passenger cars and vans	0.00	9.00	1.17	0.88
Living area	Surface area, m ²	10.00	500.00	98.19	52.47
Adults	Number of persons 18 years and older	1.00	6.00	1.77	0.65
Children	Number of persons younger than 18 years	0.00	8.00	0.40	0.88

$$EXP_i^k = \alpha + \beta S_i + \gamma B_i + \delta E_i + \theta R_i + \varepsilon_i,$$

$$CF_i^k = \alpha + \beta S_i + \gamma B_i + \delta E_i + \theta R_i + \varepsilon_i,$$

where α is the constant and ε_i is the error term. The dependent variables EXP_i^k denote the amount of money that household i allocates to expenditure category k , and CF_i^k is the carbon footprint of household i from consumption in expenditure category k . The set of independent explanatory variables includes demographic characteristics (S_i), building characteristics (B_i), occupational and economic factors (E_i), and spatial characteristics (R_i).

Continuous and discrete explanatory variables are listed in Table 1, and dummy variables in Table 2. Age, education and occupation are the characteristics of the survey respondent for each household. The variable Age is grouped into seven categories. The variable Region is based on the NUTS 2 classification. The original *Urban_rural* variable includes seven urban/rural classes (Helminen et al., 2014), but in this study four rural classes were grouped into two (dense rural and dispersed rural) to ensure a sufficient number of observations in each *Urban_rural* class under every Region class. In addition, *Region x Urban_rural* interaction variables were created.

Several model specifications were tested (see Appendix A, Table A.5.). Based on the model validation, the results shown in Section 3 are estimated with Model 9. Furthermore, the same model was estimated for more detailed (4-digit level) consumption expenditure categories (104 commodities) to gain additional insight into consumption patterns.

In some studies, e.g., in Ala-Mantila et al. (2014) and Fremstad et al. (2018), the consumption CF is estimated using consumption expenditure as an explanatory variable. Consumption expenditure and the CF are highly correlated, which is to be expected, as the expenditure for each commodity is used in the calculation of the corresponding CF (in the data of this study, the correlation varied between 0.58 and 0.99). As the consumption CF is calculated by multiplying the expenditure by the emissions intensity, regressing the CF on consumption expenditure poses a possible endogeneity problem that could bias the results.

Money income, that is, household gross income less imputed income items, is used as an income variable. Using money income evens out the differences between renter and owner-occupied households, increasing the robustness of the results.

Table 2

Explanatory dummy variables. Reference categories are marked with an asterisk (*).

Age	Age <25 Age 25–34 Age 35–44 Age 45–54 * Age 55–64 Age 65–74 Age >74
Education	Higher education, Yes = 1 No = 0 *
Occupation	Farmer Entrepreneur Upper official Lower official Employee * Other (student, pensioner, unemployed, others)
House_type	Apartment * Detached house Semi-detached house Attached house Other house
Region	Helsinki-Uusimaa (HU) Southern Finland (SF) * Western Finland (WF) Northern and Eastern Finland (NEF)
Urban_rural	Inner urban * Outer urban Peri-urban Dense rural (local rural centres and rural areas close to urban areas) Dispersed rural (rural heartland and sparsely populated rural areas)
Region x Urban_rural	SF x Urban_rural *, Region x Inner urban *

Some of the households consume more and some less than their money income. This results from differences in savings and debt among the households. Therefore, the amount of debt is included in the model. The mean difference between money income and consumption expenditure is 3,636 €, showing that at the aggregate level, households save some fraction of their income (similar to the observation in Gill and Moeller (2018)).

Several checks related to the assumptions of the regression analysis were conducted to ensure the robustness of the results. The correlation between the continuous explanatory variables varied between 0.19 and 0.52 (see Table A.1. in Appendix A). Due to

heteroskedasticity in all of the 12 regression models (see Table A.2. in Appendix A for Breusch-Pagan test statistics), the heteroskedasticity-consistent estimators (White, 1980) of the variance-covariance matrix are used in the estimations. The variance inflation factors (VIFs) were computed to quantify possible multicollinearity (all values below 10).

The goodness of fit (R^2) of the models varied from 0.20 (travel) to 0.78 (housing) (see Table 3 in Section 3.1), which can be considered fairly good. Housing expenditure had the highest R^2 , likely influenced by the location dependence of housing prices. Travel expenditure had the lowest R^2 , which indicates that the model leaves out some important determinants of travel expenditure.

2.4. Limitations

There are limitations related, first, to the HBS data, which include only actual household consumption. In addition to their “out of pocket expenditure”, households benefit from public services, such as education and health care. These services are not included in the carbon footprint categories calculated from household expenditure. Furthermore, the HBS data on alcohol and tobacco cover only one-third of the expenditure on these items reported in the national accounts. The acquisition of durables (e.g., cars, some furniture, freezers) is reported for the previous 12 months, which causes variation between households in the consumption of certain commodities. At the aggregate level, this variation does not matter, but it elevates the standard deviations. These are common limitations of HBS data, and solving them would require enhanced compilation of statistics that is out of scope of this study.

The second source of uncertainty in CF analysis is the calculation of GHG intensities. The aggregation of 148 industries and 229 products in the ENVIMAT model is rather detailed in comparison to the tools utilised in CF analyses globally. Nevertheless, the aggregation may still lead to some errors. The GHG intensities are calculated for average products in the Finnish markets, including

both domestic and imported ones, and therefore, it is not possible to differentiate “eco-friendly” commodities from “regular” ones. That is, the model assumes homogeneity of products within each of the 65 commodities. For example, a similar level of expenditure may represent the purchase of a few expensive goods or many cheap ones. The calculation method also assumes linearity between expenditure and the CF. This is a well-known limitation of EEIO models. Violations of the assumptions mentioned above may bias the results when CFs of different types of households are compared.

The CF of housing contains possible uncertainty from two sources: price level and GHG intensities. Housing prices (real rents and calculated, owner-occupied house rents) vary across the country. Housing prices in Helsinki-Uusimaa are higher than the national mean, while prices in other NUTS 2 regions are lower. This increases the calculated CF of housing in Helsinki-Uusimaa compared to that of other regions, even though higher prices do not necessarily cause higher emissions. The second source of uncertainty is related to the GHG intensities of rents (including utilities as part of the rent) and district heating. Because the ENVIMAT model provides estimates for the average nation-level intensities, it omits regional differences in CFs resulting from varying levels of fuel use for district heating. As a result, the housing CFs may be biased upwards in the Helsinki-Uusimaa region and in inner urban areas. The CFs may be biased downwards in Southern, Northern and Eastern Finland and in dense and dispersed rural areas. The implications of these possible sources of biases have been taken into account when interpreting the results. For further discussion on the implications of limitations and scope in consumption-based CF studies, see Heinonen et al. (2020).

3. Results

3.1. Demographic characteristics

The impact of households' demographic heterogeneity on their average consumption patterns is introduced in this section. Table 3 shows the results regarding total consumption expenditure and

Table 3
Regression results of expenditure related to demographic characteristics.

	Dependent variable					
	Total	Food	Housing	Travel	Services	Tangibles
Constant	2,648.48* (1,590.10)	480.75** (222.77)	1,812.83*** (292.24)	−726.34 (973.17)	−396.49 (458.76)	295.64 (501.18)
Adults	1,695.15** (845.29)	1,450.98*** (101.61)	138.70 (140.30)	−951.60 (601.16)	−37.78 (252.24)	799.26*** (288.92)
Children	1,002.89** (508.88)	936.97*** (98.58)	122.02 (101.30)	−548.08* (325.23)	225.46 (186.27)	580.79*** (175.75)
Age < 25	745.79 (1,134.21)	−554.89*** (157.15)	−379.40 (236.21)	763.42 (655.55)	707.99** (327.97)	887.70* (505.57)
Age 25–34	−308.94 (1,064.02)	−461.95*** (133.94)	−324.06 (207.41)	466.66 (619.46)	693.06** (296.45)	−683.25* (403.27)
Age 35–44	1,078.88 (1,249.89)	53.57 (158.96)	−464.11** (220.33)	130.67 (713.34)	1,016.53*** (364.20)	−33.03 (459.35)
Age 55–64	−1,365.35 (1,002.85)	131.60 (143.66)	−22.67 (176.34)	−345.96 (629.24)	−408.36 (275.70)	−524.22 (450.51)
Age 65–74	245.78 (1,101.42)	390.75*** (146.25)	186.16 (202.72)	66.80 (660.10)	246.26 (374.53)	−205.37 (442.48)
Age > 74	−2,959.20*** (1,006.16)	24.26 (155.39)	213.22 (219.47)	−1,205.00** (578.92)	−62.90 (296.94)	−543.23 (410.83)
Spatial controls	Yes	Yes	Yes	Yes	Yes	Yes
Econ. & building controls	Yes	Yes	Yes	Yes	Yes	Yes
Observations	3490	3490	3490	3490	3490	3490
R^2	0.60	0.54	0.78	0.21	0.38	0.32
Adjusted R^2	0.59	0.53	0.78	0.20	0.37	0.31
Residual std. error (df = 3446)	417,380.20	54,604.92	74,931.86	258,674.20	132,682.50	140,739.70
F statistic (df = 43; 3446)	122.20***	96.52***	290.88***	21.99***	49.28***	37.80***

Notes: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Significant values are in bold. Standard errors are in parentheses. Reference group: Age 45–54.

expenditure on food, housing, travel, services, and tangibles. Including the age group of the household respondent instead of a more aggregated classification illustrates how the life phase affects expenditure patterns, even when other explanatory variables are controlled for.

As expected, total expenditures increase with the number of people living in the household. The relationship is mostly linear, as the second-order polynomial was not statistically significant when tested. Expenditures are more affected by the number of adults living in the household than by the number of children. No statistically significant differences were found regarding the age of children in the household. Within total expenditure, expenditure for a child corresponds to 0.59 of that for an adult. However, the numbers of adults or children are not statistically significant determinants of housing and service expenditure. Moreover, the presence of children in the household has a (weakly) negative statistical effect on travel expenditure. The children/adult expenditure ratios were 0.65 for food and 0.73 for tangibles.

Generally, the food expenditure of younger households tends to be lower than that of the reference group (age 45–54). Nevertheless, services expenditures are higher in younger households, which could partly be caused by higher consumption of restaurant services.² There is no statistically significant difference in travel expenditures, except that the oldest households consume much less in this category than the reference group. Regarding travel abroad, the age groups from 25 to 44 spend significantly more on overseas travel tickets. There were no differences among age groups in terms of package tour expenditure.

The youngest household group had a statistically significantly higher consumption of tangibles than that of the reference group. According to detailed 4-digit results, this difference arises mainly from the consumption of mobile devices, entertainment, games and personal care. Moreover, more household appliances and furniture are likely acquired when people move away from their childhood homes. On the other hand, expenditure on tangibles is lower for households with respondents in the 25–34 age group than for those in the reference group. At a later age, there are no statistically significant differences in the consumption patterns of tangibles at the aggregate level.

3.2. Occupational, economic and dwelling characteristics

This section focuses on the economic and occupational characteristics of the respondent and dwelling type of the household (Table 4). A detailed set of explanatory variables is used, such as the number of cars and type of dwelling. Additionally, the inclusion of dummy variables on the higher education and occupational status of the respondent yields a more varied picture of the effect of occupational position than the view that emerges when just one variable is used.

As shown in reviews by Wiedenhofer et al. (2018), Druckman and Jackson (2016), and Zhang et al. (2015), higher income increases consumption opportunities, resulting in larger CFs (see Section 3.4). The interpretation of the two income terms is the following: at the sample mean income level (39.5 k€), the impact of an additional 1,000 € on total expenditure is $(478.22 \times (39.5 + 1) - 0.80 \times (39.5 + 1)^2) - (478.22 \times 39.5 - 0.80 \times 39.5^2) = 414.22$ €. This effect varies nonlinearly over income levels such that the marginal propensity to consume decreases with income. In other words, households save more of the added

income as their income level rises.

Larger homes result in higher expenditures on housing, services, and tangibles. For instance, the consumption of services is related to insurance and the normal upkeep of the premises. The number of cars is associated with higher services consumption, mainly due to vehicle insurance. The number of cars has a statistically significant negative effect on expenditures on travel abroad (including ticket purchases). However, the variables for income, the number of children, two age groups, occupational status, and one residential location (outer urban areas in Helsinki-Uusimaa) also had a statistically significant positive or negative effect on travel abroad.

Higher education results in higher total expenditure, with the consumption of this group directed towards food, housing, and services. Services expenditure is statistically significantly higher in the accommodation, education, hairdressing, and personal grooming services categories for more educated respondents.

The consumption expenditure of households of higher socio-economic status (entrepreneurs and upper and lower officials) is higher than of the reference group (employees). For instance, in the case of officials, more expenditure is allocated to the consumption of tangibles, which may be due to the need to indicate a higher socio-economic status. A statistically significantly higher consumption of tangibles was related to spending on major household appliances, glassware, and goods for personal care. A similar logic may apply for the higher services consumption of entrepreneurs and officials, who spend more, for example, on restaurant services and leisure activities. Furthermore, the mobility of entrepreneurs is reflected in the highly statistically significant coefficient of travel. On the other hand, farmers have statistically significantly lower housing, travel and tangibles expenditure than that of the reference group. No clear patterns arise in terms of the dwelling type.

3.3. Place of residence and the effect of region and urban/rural typology

3.3.1. Effects of choice of spatial variables and socio-economic controls

In this section, the effect of the choice of spatial variables in the model is shown in terms of region (NUTS 2), urban/rural typology, and their interactions.

The geographical diversity of consumption patterns is shown by including indicator dummies for each of the four NUTS 2 regions in mainland Finland (Helsinki-Uusimaa (HU), Southern Finland (SF), Western Finland (WF), and Northern and Eastern Finland (NEF)). Southern Finland is the reference category, since its mean values are closest to the expenditure category sample means. Model 6 in Table A.5. Appendix A shows that consumption is highest in the HU region, and the difference related to the reference region is highly statistically significant at the 1% level. However, there is no statistically significant difference with the other two regions. The model fits the data rather well, with an R^2 of 0.59.

The second classification uses urban/rural typology (Helminen et al., 2014) to define the type of area where the household resides. This study differentiates five urban/rural classes (see Section 2.3 for details). The inner urban area is chosen as the reference category, as it is expected that consumption is highest in these areas (Model 7 in Table A.5. Appendix A confirms this assumption). As anticipated, consumption tends to be lower in rural areas than in urban areas. All variables are statistically significant.

The geographical region and urban/rural typology are considered simultaneously in Model 8 in Table A.5. (Appendix A). The coefficient of the Helsinki-Uusimaa region is still highly statistically significant, and its sign and magnitude remain similar to those in Model 6. However, when the region is controlled for, consumption in outer and peri-urban areas is not significantly different from

² According to detailed 4-digit results (see Section 2.3), expenditure on catering services is statistically significantly higher in age groups from 24 years up to 44 years than in the reference group.

Table 4
Regression results of expenditure related to socio-economic and dwelling characteristics.

	Dependent variable					
	Total	Food	Housing	Travel	Services	Tangibles
Constant	2,648.48* (1,590.10)	480.75** (222.77)	1,812.83*** (292.24)	−726.34 (973.17)	−396.49 (458.76)	295.64 (501.18)
Income (k€)	478.22*** (49.24)	28.99*** (4.84)	40.43*** (6.43)	172.72*** (24.65)	120.31*** (11.70)	87.71*** (22.79)
Income ² (k€)	−0.80*** (0.17)	−0.04** (0.02)	−0.06*** (0.02)	−0.33*** (0.04)	−0.22*** (0.03)	−0.08 (0.10)
Debt (k€)	29.57*** (6.60)	0.45 (0.72)	10.86*** (1.38)	6.55 (4.28)	6.57*** (1.95)	4.26* (2.58)
Number of cars	2,465.46*** (686.72)	−123.09** (60.48)	−127.57 (99.28)	2,327.97*** (555.19)	420.82*** (147.55)	84.25 (184.97)
Living area (m ²)	115.09*** (11.40)	3.00* (1.55)	85.41*** (3.50)	6.50 (6.68)	8.52*** (2.94)	8.16** (3.32)
Higher education	1,236.53* (720.29)	191.48** (89.34)	449.88*** (131.26)	−177.72 (393.43)	540.58** (265.47)	280.22 (225.27)
Farmer	−4,953.70** (2,002.48)	329.62 (384.17)	−995.40** (485.23)	−2,105.05* (1,253.53)	−788.68 (538.52)	−1,190.48* (635.83)
Entrepreneur	5,958.58*** (1,608.38)	−218.72 (273.63)	665.71** (326.72)	2,177.62** (1,100.66)	1,571.10*** (472.05)	924.65 (580.12)
Upper official	3,783.23*** (1,211.62)	−49.05 (154.32)	354.44 (219.24)	145.89 (752.18)	1,922.76*** (403.34)	1,093.23** (430.95)
Lower official	2,984.48*** (965.19)	37.40 (129.64)	178.48 (163.60)	826.87 (611.35)	963.59*** (272.69)	927.66*** (293.37)
Other	849.63 (910.12)	−310.33** (128.91)	297.59* (173.51)	36.04 (544.24)	555.60** (244.48)	76.95 (311.03)
Detached house	−1,583.11 (1,102.67)	342.48** (136.62)	−969.46*** (230.01)	−438.16 (610.80)	72.96 (504.18)	−301.21 (399.31)
Semi-detached house	623.54 (1,653.81)	333.63 (210.00)	190.61 (324.61)	−413.43 (974.88)	443.04 (527.81)	547.89 (598.41)
Attached house	757.57 (834.67)	107.65 (110.93)	287.27* (162.94)	−243.05 (498.69)	454.83 (287.37)	−164.54 (282.49)
Other house	−4,524.01* (2,469.44)	−181.53 (239.10)	−2,183.78** (925.38)	−1,401.26 (1,405.70)	405.29 (728.97)	−1,009.77** (505.01)
Demographic controls	Yes	Yes	Yes	Yes	Yes	Yes
Spatial controls	Yes	Yes	Yes	Yes	Yes	Yes

Note: *p < 0.1, **p < 0.05, ***p < 0.01. Significant values are in **bold**. Standard errors are in parentheses. Reference groups: No higher education, Employee, and Apartment.

consumption in inner urban areas. Nevertheless, the results show the difference in urban and rural consumption even when the region is controlled for.³ The model fit ($R^2 = 0.59$) is the same as in Models 6 and 7, but the specification provides more details regarding the region and urban/rural type of the living area.

Model 9 includes the interactions of the region and urban/rural classes to reflect the added impact of living in a specific type of area (urban/rural) in a specific NUTS 2 region. The underlying hypothesis is that consumption is, for example, different in the outer urban areas of SF than in the outer urban areas of WF. In Model 9, the indicators for the HU and WF regions are still statistically significant. On average, consumption in outer and peri-urban areas and dispersed rural areas is significantly different from that in inner urban areas. Some of the region and area combinations show a combined impact on consumption in comparison with the reference combination of inner urban area in the SF region.⁴

³ On average, a household in a dense rural area of the region of Northern and Eastern Finland consumes $\text{abs}(58.81 - 2,118.74) = 2,059.93$ € less than a household in an inner urban area of the Southern Finland region. A similar household living in the Helsinki-Uusimaa region in a dense rural area consumes $\text{abs}(4,093.85 - 2,118.74) = 1,975.11$ € more than a household in the reference region and area.

⁴ The impact on consumption from living in the reference location is zero. Instead, a household in an outer urban area in Southern Finland consumes 4,333.06 € less than a household in the same region but in an inner urban area. A household living in an outer urban area in the Western Finland region consumes $\text{abs}(-2,353.36 - 4,333.06 + 4,610.27) = 2,076.15$ € less than a similar household in the reference location. Analogously, the corresponding impact from living in an outer urban area in Helsinki-Uusimaa is $\text{abs}(2,400.84 - 4,333.06 + 5,001.89) = 3,069.67$ €.

The impact of the NUTS 2 region and urban/rural typology on an average household's total expenditure are shown in Fig. 1. The leftmost bars show the average (NUTS 2) region-specific impact (Model 6); the second set of bars show the average impact of the urban/rural class (Model 7); the third set of bars show the combined impact of region and urban/rural class (Model 8); and the rightmost bars include the region and urban/rural class interactions (Model 9).

If one includes only the region or urban/rural indicators, the conclusions drawn on the estimates could be biased. In other words, it is necessary to consider regional heterogeneity with respect to the urban/rural classification. This is illustrated in Fig. 1, where the rightmost bars, which represent the estimates with the interaction terms (Region x urban_rural), are compared to the estimates without the interaction terms (Region + urban_rural).

In addition to the selection of the appropriate spatial variables, inclusion or exclusion of other control variables affects the parameter estimates. Model 10 in Table A.5. (Appendix A) shows, as an example, that excluding socio-economic control variables has no effect on the R^2 . Additionally, the significance levels and signs of the spatial variables remain the same, but the magnitudes of the parameter estimates may vary. The analysis, therefore, suggests that the spatial variables may capture part of the variation associated with socio-economic characteristics, as these may affect the choice of residential location.

3.3.2. Influence of place of residence on consumption patterns

The detailed regression results on the impact of the NUTS 2 region and urban/rural class on households' consumption

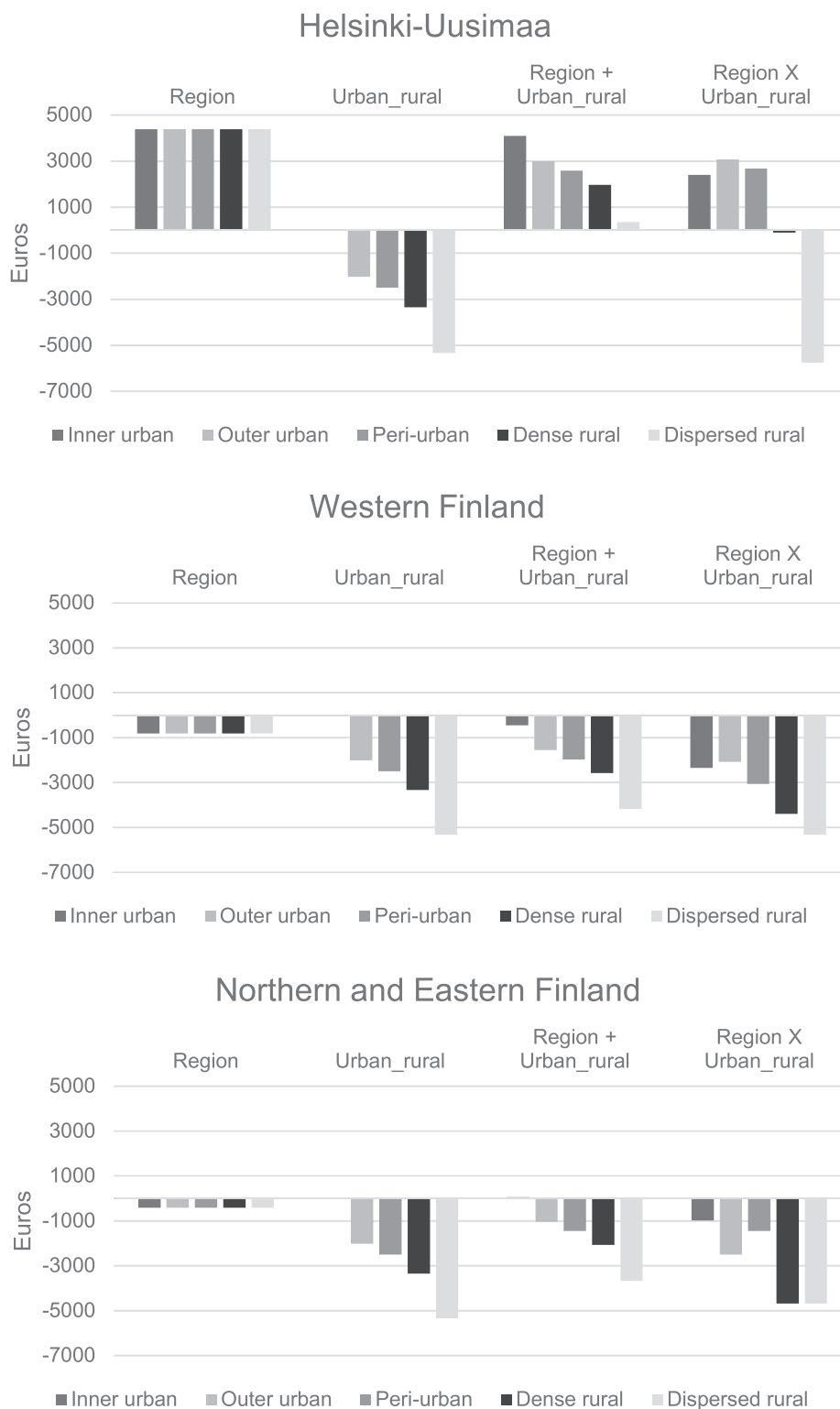


Fig. 1. Impact of NUTS 2 region and urban/rural class on the total expenditure of an average household, grouped by region.

expenditure are presented in Table A.3. (Appendix A). The regression results are based on the specification in Model 9 (Table A.5. in Appendix A). Overall, the main effects of the region indicators show that consumption expenditures are highest in Helsinki-Uusimaa (HU) and are mainly driven by housing expenditures. However,

when the total effect of all spatial variables is considered, expenditures are higher in urban areas but not in rural areas of HU. The travel and tangibles expenditures seem to be statistically significantly lowest in Western Finland (WF), although when the total effect of all spatial variables is considered, there is variation among

areas within WF. There are no statistically significant differences in any of the commodity bundles between Northern and Eastern Finland (NEF) and Southern Finland (SF).

Generally, the statistically significant effects of the urban/rural classes show that total consumption tends to be highest in inner urban areas. Tangibles consumption seems to be highest in dense rural areas. However, when all spatial parameter estimates are considered, in all dense rural areas, tangibles consumption is lower than in the reference category. It is clear that housing expenditure is higher in urban areas than in rural areas.

A closer look at the combinations of NUTS 2 regions and urban/rural classes reveals some differences. The interactions describe the added impact of a specific region and urban/rural class combination on their average impact. For example, ignoring the interaction of the outer urban area and WF, the results would imply that the expected average consumption in this combination is $\text{abs}(-456.9 - 1,096.18) = 1,553.08 \text{ €}$ less than in the reference combination of inner urban area in SF (see Model 8 in Table A.5., Appendix A). When the interaction is taken into account, the results indicate that the expected consumption with this specific NUTS 2 urban/rural combination is actually $\text{abs}(-4,333.06 - 2,353.36 + 4,610.27) = 2,076.15 \text{ €}$ lower than that in an inner urban area of SF. To summarise, although the effect and significance of spatial variables is moderate compared with those of other explanatory variables, the model comparison reveals spatial differences that may be undetected in approaches that use a lower spatial resolution.

3.4. Carbon footprints of consumption expenditure categories

The CF analysis results follow the consumption expenditure results quite closely (Table A.4. in Appendix A and Table 5 in Section 3.5). Since the GHG intensity of every commodity is larger than zero, higher expenditure translates into a higher CF. Additional income increases the CF most in the travel category and least in the food category. The total CF increases with the number of people living in the household, and the footprint is more affected by the number of adults than that of children. Regarding the total CF, a child's CF corresponds to 0.59 of an adult's. Among the statistically significant consumption categories, the child/adult CF ratio was highest in the tangibles (0.93) and the lowest in the housing (0.53) category. In the tangibles category, the child/adult CF ratio is higher in than child/adult expenditure ratio (0.73), indicating that the carbon intensity of products purchased is different in households with children than in those without children.

The CF results follow those on expenditure in terms of how the carbon footprint of the food category tends to be lower for the younger household group (<35-year-olds) than for the reference group (age 45–54). The carbon footprint from services is higher for younger households and lower for older households than that of the reference group. There are no statistically significant differences in the carbon footprints from travel, apart from the lower CF of the oldest households. The youngest household group has a statistically significantly higher CF from tangibles consumption than that of the reference household group.

Additionally, the findings on socio-economic variables mostly follow those from the expenditure model. Higher education results in a higher total CF, even if income, occupation, and spatial variables are controlled. The CFs from housing and services consumption for households with higher education are statistically significantly higher than those of households without higher education. The CF from total consumption of households of higher socio-economic status (higher and lower officials) is the highest among all socio-economic groups. In particular, the CF from tangibles and services consumption is higher, following the patterns observed in the

expenditure analysis. At the same time, farmers have a lower CF than that of the reference group for every category except food. Interestingly, entrepreneurs' higher consumption of travel does not translate into higher travel CF. The difference is likely explained by lower consumption of fuels but higher consumption of maintenance, repairs and expenses for a vehicle provided as a benefit in kind. However, fuel costs may be covered by the company providing the benefit. In addition, entrepreneurs' expenditure on overseas travel tickets is higher than that of the reference group.

The analysis of spatial variables shows that the effect of the region (NUTS 2) and urban/rural class is similar to that observed for expenditure patterns. In the Helsinki-Uusimaa region, the CF of housing is statistically significantly higher than that in the reference region, partly because of the higher housing prices. In outer urban areas, households consume fewer GHG-intensive services than in inner urban areas. The same holds for peri-urban areas in the case of the CF from tangibles. The total CF is higher in dense rural areas, driven by the higher CFs from travel and tangibles. However, the interactions of regional variables in dense rural areas have the opposite effect on the travel and tangibles CFs (except travel in dense urban areas in Helsinki-Uusimaa) and therefore decrease the total effect.

The interaction variables reveal some regional differences among urban/rural classes. Dense rural areas in Western Finland (WF) and Northern and Eastern Finland (NEF) have a lower total CF and lower CFs from food, housing and travel consumption than those of the reference combination. While the dense rural variable, in general, seems to be associated with an increase in the total CF and the CF from travel, households living in dense rural areas of the WF and NEF regions have lower travel CFs than households living in dense rural areas in other NUTS 2 regions. As the examples show, the net effect of all spatial variables should be considered in investigations of the CF characteristics of a specific combination of region and urban/rural class.

3.5. Comparison of expenditure and carbon footprints

The signs of the estimated expenditure and CF parameters are used to summarise the findings on expenditure and CFs. The comparison can be interpreted from a decoupling perspective. If the change in expenditure is positive but the footprint change is negative, compared to the reference group, this is interpreted as an absolute decoupling of expenditure and the carbon footprint. The opposite – a negative expenditure change and positive CF change – would indicate negative decoupling. Table 5 summarises the directions of the effect of each explanatory variable on expenditure and the CF.

Table 5 shows that with one exception, the signs of the statistically significant expenditure and CF coefficients point in the same direction. Hence, the results provide little evidence of an absolute decoupling of expenditure and the CF. Nor is evidence found of negative decoupling. The exception is entrepreneurs and travel. Compared to the reference group (employees), entrepreneurs have higher expenditure but a lower CF from travel. The 4-digit results reveal that relative to employees, entrepreneurs have statistically significantly lower expenditure on fuel and spare parts but higher expenditure on a vehicle provided as a benefit in kind and on overseas travel tickets.

There are limitations to consider in interpreting the findings above. First, the data provide a snapshot of consumption patterns and CFs. Therefore, they illustrate how CFs vary due to different consumption patterns (the product-mix effect) but not how decoupling may result from lowering the carbon intensity of production over time (the technology effect). However, it is not evident that consumption patterns would remain unchanged while the

means and efficiency of production change and efficiency improves.

Second, the analysis in this study can only reveal absolute decoupling, i.e., whether the signs on expenditure and the CFs are different. When the signs for both expenditure and a given CF are positive, relative decoupling is still possible if the change in expenditure is greater than the change in the CF. However, this cannot be seen from the summary.

Third, the results in Table 5 are based on a model in which GHG emissions intensities vary between commodities but do not differentiate between products within each of the aggregated commodity groups. Therefore, consumption of products with lower- or higher-than-average emissions intensities is not shown.

4. Discussion and conclusions

4.1. Drivers of consumption and carbon footprints

Two analyses were conducted with an extensive set of demographic, socio-economic, and spatial explanatory variables: first on expenditure and then on the derived CFs. In contrast to previous studies focusing on only CFs, this study first analyses the primary expenditure patterns reflecting the actual choices and activities of households without the uncertainties involved in the CF analysis. The separate analyses mainly point to similar drivers of expenditure and CFs at the level of aggregated commodity groups and total

expenditure/CFs. The role of income was prominent, and demographic as well as socio-economic characteristics were related to the differences in consumption patterns. The results, therefore, mainly resonate with those of previous literature on the drivers of the consumption-based CF (e.g., Zhang et al., 2015). Nevertheless, the variable and model selection reveals novel empirical details and modelling considerations.

Consumption patterns and the related CFs differed among households across the explanatory variables: for instance, travel consumption in the case of age groups, consumption of tangibles among households with children, and consumption of goods and services among certain occupational groups. The differences can be interpreted as indications of the (perceived) requirements of each life phase, social norms in society and among peers, and everyday living arrangements affected by time pressures (Wiedenhofer et al., 2018) related to combining work and family life. As Smetschka et al. (2019) discuss, time squeeze combined with access to affordable but carbon-intensive means of managing everyday activities can contribute to larger carbon footprints.

4.2. Effect of spatial variables

The results of this study show that when socio-economic explanatory variables are controlled for, certain spatial variables or their interactions have a statistically significant effect on household consumption patterns (Section 3.3). For instance, living

Table 5
Summary of variables' effects on expenditure and carbon footprints.

	Dependent variable											
	Total		Food		Housing		Travel		Services		Tangibles	
	exp.	CF	exp.	CF	exp.	CF	exp.	CF	exp.	CF	exp.	CF
Constant	+	+	+	+	+	+	-	-	-	-	+	+
Income (k€)	+	+	+	+	+	+	+	+	+	+	+	+
Income ² (k€)	-	-	-	-	-	-	-	-	-	-	-	-
Debt (k€)	+	+	+	+	+	+	+	+	+	+	+	+
Number of cars	+	+	-	-	-	+	+	+	+	-	+	+
Living area (m ²)	+	+	+	+	+	+	+	+	+	+	+	+
Adults	+	+	+	+	+	+	-	+	-	-	+	+
Children	+	+	+	+	+	+	-	-	+	-	+	+
Age < 25	+	-	-	-	-	-	+	-	+	+	+	+
Age 25–34	-	-	-	-	-	-	+	-	+	+	-	-
Age 35–44	+	-	+	+	-	-	+	+	+	+	-	-
Age 55–64	-	-	+	+	-	+	-	-	-	-	-	-
Age 65–74	+	-	+	+	+	+	+	-	+	-	-	-
Age > 74	-	-	+	-	+	+	-	-	-	-	-	-
Higher education	+	+	+	+	+	+	-	+	+	+	+	+
Farmer	-	-	+	+	-	-	-	-	-	-	-	-

Entrepreneur	+	-	-	-	+	-	+	-	+	+	+	+
Upper official	+	+	-	-	+	+	+	+	+	+	+	+
Lower official	+	+	+	-	+	-	+	+	+	+	+	+
Other	+	-	-	-	+	+	+	-	+	+	+	+
Detached house	-	-	+	+	-	-	-	+	+	-	-	-
Semi-detached house	+	-	+	+	+	+	-	-	+	+	+	+
Attached house	+	+	+	+	+	+	-	-	+	+	-	+
Other house	-	-	-	-	-	-	-	-	+	+	-	-
Helsinki-Uusimaa (HU)	+	+	+	-	+	+	-	-	+	+	+	+
Western Finland (WF)	-	-	+	+	+	+	-	+	+	+	-	-
North. and East. Finland (NEF)	-	+	+	-	+	+	+	+	-	-	-	-
Outer urban	-	-	-	-	-	-	-	-	-	-	-	-
Peri-urban	-	-	-	-	-	-	-	+	-	-	-	-
Dense rural	-	+	+	+	-	+	-	+	-	-	+	+
Dispersed rural	-	-	-	-	-	-	+	+	-	-	-	-
WF x outer urban	+	+	+	+	+	-	+	+	-	-	+	+
WF x peri-urban	+	+	+	+	+	-	+	+	-	-	+	+
WF x dense rural	-	-	-	-	-	-	+	-	-	-	-	-
WF x dispersed rural	+	+	-	-	+	-	+	-	-	-	+	+
NEF x outer urban	+	+	-	+	-	-	+	+	+	+	+	+
NEF x peri-urban	+	+	+	+	-	-	+	+	-	-	+	+
NEF x dense rural	-	-	-	-	-	-	-	-	-	+	-	-
NEF x dispersed rural	+	+	+	+	+	+	-	-	+	-	+	+
HU x outer urban	+	+	+	+	-	-	+	+	+	+	-	-
HU x peri-urban	+	+	+	+	-	-	+	+	-	-	+	+
HU x dense rural	-	-	-	-	-	-	+	+	-	-	-	-
HU x dispersed rural	-	-	-	-	-	-	-	-	-	-	-	-

Notes: Statistically significant ($p < 0.1$) figures are in **bold**, and combinations with significant values for both expenditure and CF are **bolded and highlighted**. Reference groups: Age 45–54, No higher education, Employee, Apartment, Southern Finland (SF), Inner urban, SF x *Urban_rural*, *Region* x Inner urban.

in urban areas in the Helsinki-Uusimaa region increases total expenditure, which is driven especially by housing and travel in outer and peri-urban areas.

The novelty of the analysis regarding the spatial drivers is the use of both region (NUTS 2) and urban/rural typology variables as well as their interactions. Thus, the resolution of spatial variables in the analysis is much higher than that in previous studies. Hence, the analysis distinguishes the effect of specific characteristics of areas resulting from the combination of which part of the country and what type of area (urban/rural classification) in question. Especially in urban areas, the number of observations allows for the highlighting of differences across area types and parts of the country.

Previous studies focusing on the impact of either region or area type on the CF have used more general regional classifications. Categorical variables have included, for instance, NUTS 2 (Ivanova et al., 2017),⁵ five classes of municipalities according to population size (Gill and Moeller, 2018), and a classification of municipalities according to their urbanity as in Ala-Mantila et al. (2014) and Heinonen et al. (2013). The same urban/rural classification used in this article has been previously used in Ala-Mantila et al. (2016) and Ottelin et al. (2015). However, the analyses Ottelin et al. (2015) were restricted to three classes of urban areas. Additionally, travel-related urban zone classification in the Helsinki metropolitan area has been used in an analysis of carbon-mitigation policies (Ottelin et al., 2018).

As many of the listed studies emphasise, consumption patterns are complex, and therefore, detailed spatial data are required to provide an adequate understanding of the dynamics. A high-resolution model is used in this study, and the model comparisons (Section 3.3 and Tables A.5. and A.6. in Appendix A) and Fig. 1 of this article support the argument. More specifically, a high-resolution classification of area typology, geographical location and the interactions of these variables should be considered in data collection and on the analysis of the role of location in expenditure patterns and the derived CFs. This is especially relevant for region-specific policies aiming to address the consumption-based CF, which, e.g., Wilting et al. (2020), call for. Thus, the modelling considerations are relevant beyond Finland.

In addition to the impact of model selection regarding spatial variables, the inclusion or exclusion of socio-economic variables in the model also affects the results and conclusions on the role of spatial variables. Fremstad et al. (2018) observe that while the explanatory power of their model remains unchanged, the inclusion of socio-economic controls alters the parameter estimates for spatial variables in their analysis of per capita CFs. The model comparison in this study (Tables A.5. and A.6. in Appendix A) shows that the exclusion of socio-economic controls from the expenditure and CF models slightly decreases the R^2 and affects the parameter estimates and their significance. Omitting socio-economic controls may therefore magnify the effect of spatial variables. While socio-economic characteristics have been included in some studies and found to be significant (e.g., Minx et al., 2013), some scholars have omitted them beyond, e.g., expenditure and the number of persons in the household (Ala-Mantila et al., 2014).

Heinonen et al. (2013) write about “situated lifestyles”, referring to how the everyday environment shapes consumption patterns. However, analysing consumption patterns or the CF with spatial variables only or with a limited number of variables on respondents’ life phase and socio-economic characteristics could

possibly lead to biased conclusions on the importance of area type. Previous literature has also discussed the issue of self-selection, i.e., that people with certain preferences favour specific types of area, which may affect, e.g., travel patterns (Czepkiewicz et al., 2018). See also (Næss, 2016) for a discussion of causality related to the built environment and human actions. Consumption-based policy development in cities, municipalities and regions could make use of analysis such as the one in this study to recognise similar but also area- and region-specific characteristics of consumption patterns. The high-resolution Finnish datasets allow analysis of NUTS 2 region, urban/rural category, and their interactions, although increasing the number of observations in future HBS datasets would further improve opportunities to analyse spatial effects.

To conclude, the results provide novel empirical findings and more generally show the contribution of high-resolution variables for the quality of the analysis. Nevertheless, the role of spatial variables, in general, is in line with that in previous research showing that consumption patterns and the derived CFs differ among areas but that the differences are rather small as previously reported in a Finnish study by Ala-Mantila et al. (2016), in Germany (Gill and Moeller, 2018), and in the UK (Minx et al., 2013). The small differences found in the study at hand may reflect quite equal opportunities to travel, spend time, and buy products and services across any type of area in Finland. The results should be interpreted as an example of an affluent country with well-established public welfare services.

4.3. Policy implications of findings

Consumption patterns are of interest as there are studies (e.g., Girod et al., 2014 on a global scale and Moran et al., 2018 focusing on European Union) modelling how changes in consumption *could* decrease household consumption footprints *if shifts in consumption patterns occurred* (e.g., type of food consumption and use of transport modes) and, on the other hand, studies that show the actual consumption patterns and drivers of expenditure and related GHG emissions. Based on the literature review in this article, a number of viable actions to decrease the CF from household consumption, as well as demographic, socio-economic and spatial drivers of the CF, have been identified. However, the policy mixes (Nissinen et al., 2015) required to effect changes in consumption patterns need to be strengthened. Hoekstra and van den Bergh (2002) conclude that changes in demand (the level effect) tend to outpace the effect of technological advances, and consumption may rebound (e.g., Chitnis et al., 2014). In other words, the volumes of consumption of more efficiently produced and cheaper product may increase, or the savings may be used to purchase other products. Thus, policy development calls for improved understanding and monitoring of consumption patterns (the level and product-mix effects) and related CFs in addition to development of technological solutions.

Policy relevant conclusions regarding the spatial aspects are so that based on data from Finland in this study, the importance of the place of residence alone is rather small. Thus, one of the conclusions is that in their current form, the potential of any of the urban or rural area types to decrease the consumption-related CF in an affluent country such as Finland is alone not enough to curb this CF and policies should focus on decreasing the consumption-based CFs across areas. Nevertheless, planning of physical environments is still a potential means to steer consumption patterns, especially when cities globally are building facilities to accommodate urbanising population. For instance, the kinds of travel modes, access to daily services, and the type and size of housing that urban environments and infrastructure support and prioritise make a difference. Planning combined with other policies should be ambitious enough to curb the

⁵ Ivanova et al. include urbanity in their model. However, the level of urbanity is based on the population density of the NUTS 2 region, and therefore it does not differentiate among areas within regions.

consumption-based CFs to sustainable levels. Consumption-based accounting can help to monitor the development over time and estimate impacts of climate policies. At the same time, different area types have unique features that should be considered in the policy design. The resolution of data and modelling should be detailed enough to capture the characteristics on the scale of everyday living, which can also contribute to fairness of policies.

Although urban environments provide opportunities for low-carbon living (Wiedenhofer et al., 2018), carbon-intensive energy production in some cities and higher consumption of a number of goods and services, in general, are seen to undermine the benefits (e.g., Rosa and Dietz, 2012). In Finland, the carbon intensity of energy production is likely to have a much larger impact on spatial differences in CFs than the impact of the rather small spatial differences in consumption of tangibles and services. Along with the potential for low-carbon living, prevalent carbon-intensive forms of consumption and living are also possible or even normalised in all the studied areas, both urban and rural. For instance, car ownership may unlock certain everyday practices, and at the same time, it can create lock-ins (Ivanova et al., 2018) that are difficult to reverse due to, e.g., time constraints even if alternative modes of travel do exist. Additionally, infrastructure investments enabling specific mobility patterns have long lifespans and therefore shape the boundary conditions of everyday living arrangements for a long time into the future (Creutzig et al., 2016a). Therefore, effective policies would extend further than providing low-carbon alternatives along with mainstream practices and prevalent infrastructures.

Our initial findings on decoupling relate to how income and affluence have been widely identified as strong drivers of the CF from household consumption. At the same time, expectations for (voluntary) shifts in consumption patterns in a low-carbon direction have been discussed in the literature. Therefore, it is relevant to use empirical data, such as the HBS data in this study, to investigate whether realised, not only intended, consumption points to patterns that at the same time show growth in consumption expenditure and a decrease in the CF. As GHG intensities of commodities vary, the shifts in consumption patterns (the product-mix effect) in some consumer groups could indicate this type of decoupling. In the analysis of total expenditure and the five expenditure categories and their related CFs, little evidence of decoupling was found. However, more in-depth empirical research is needed to identify whether the decoupling of expenditure and the CF is already occurring in some consumer groups. The decoupling issue deserves more research at the subnational level and analysing household-specific data to identify low-carbon patterns and drivers. The usual suspect potentially driving less carbon intense consumption patterns would be attitudes, but as highlighted in the introduction, environmental attitudes have so far proven to be weak predictors of the CF.

The policy relevant question for future research is if decoupling of expenditure and related carbon footprint occurs, and if the transition towards a 1.5-degree path is expected to be realised while the economy and consumption continue to grow. Additionally, expectations on the role of voluntary consumer choice to shift demand and decrease negative environmental consequences may remain unfulfilled if empirical evidence of decoupling in consumption is lacking.

To conclude, the analysis in this article provides suggestions on what still needs to be further investigated regarding why and how people engage in high-carbon consumption and living in certain phases of life or lifestyles. Findings on demographic and socio-economic characteristics can point to future research directions, such as: developing policies to enhance low-carbon living in each life phase (Dubois et al., 2019), taking into account changes in demographic and population dynamics (Rosa and Dietz, 2012),

addressing trends such as an increasing share of single-person households (Ala-Mantila et al., 2016), and economies attained by sharing carbon-intensive resources (e.g., living space, means of transport) (Fremstad et al., 2018). To unpack the complexity of consumption could benefit from mapping the conditions and limitation of everyday living, as illustrated by (Wiedenhofer et al., 2018), and research approaches drawing on practice theory (Shove et al., 2012). However, regression analyses with a representative sample of a national population like the one presented in this article provide the much required overall picture of the current state and drivers of consumption and related CFs.

Author contributions

Marja Salo: Conceptualisation, writing (original draft – all sections), reviewing and editing. **Hannu Savolainen:** Conceptualisation, methodology, formal analysis, writing (original draft – Sections 2 and 3), reviewing and editing. **Santtu Karhinen:** Conceptualisation, methodology, visualisation, writing (original draft – Sections 2 and 3), reviewing and editing. **Ari Nissinen:** Conceptualisation, supervision, writing, reviewing, editing, and funding acquisition.

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Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jclepro.2020.125607>.

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