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Measuring the direct and indirect effects of low-carbon lifestyles using financial transactions☆

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ABSTRACT

This study investigates the net effect of four low-carbon lifestyle options that could potentially be adopted by many individuals and households to achieve substantial cuts in greenhouse gas emissions: not owning a car, not flying, not living in a detached house, and having a vegan diet. We evaluated the direct and indirect effects of these options on the carbon footprints of a sample of 715 individuals. Their emissions were calculated using a carbon calculator app that estimates the footprint associated with their consumption, based on financial transaction data from their bank(s) in combination with a lifestyle survey and data from official databases. This data also provides the basis for a detailed analysis of how differences in spending and greenhouse gas emissions in one consumption domain can rebound and/or spillover into other domains. Our results show that these four lifestyle options are associated with substantial net emission reductions, ranging from 0.5 to 1.5 tonnes of CO_2eq/cap/yr each. The results also suggest that, contrary to the theory of economic rebound effects, the indirect effects of these practices are related to further emission reductions in other consumption domains, except for people who do not fly, for whom we saw a very limited rebound effect. The sample has on average relatively strong pro-environmental personal norms, which limits the generalizability of the results and calls for further research.

1. Introduction

Current consumption patterns pose a great challenge for climate change mitigation, and further increases in consumption volumes risk cancelling out emissions reductions from energy-efficiency improvements and scaling up of green technologies (Pörtner et al., 2022; Rogelj et al., 2018; Bjørn et al., 2018). Ideally, firm and coordinated policies could bring about such changes at a comparatively low cost, but due to public and private opposition, in combination with strategic considerations by policymakers, stringent measures have so far failed to materialize.[1] The reluctance to address household consumption and the consequent reliance on supply-side solutions entail a risk, since the net effects of new technologies and efficiency improvements will be affected by how households adjust and adapt their consumption to these changes (Exadaktylos and van den Bergh, 2021). Research that examines behavioural responses to new technologies and provide an informed understanding of how cultural trends and lifestyles could affect consumption and interrelated environmental pressures is therefore much needed to better navigate future transitions to sustainable societies.

Research on sustainable consumption has however often lacked the means and methods to address the above issues. Access to detailed, reliable and comprehensive data on households' consumption behaviours is a long-standing difficulty of empirical research in this field (Gatersleben et al., 2002), and previous research has often relied on self-reported indicators and activities to measure the environmental impacts of consumption, which has been shown to be problematic (Tabi, 2013). The lack of reliable data that would enable more comprehensive analyses of household behaviours, has likely had a negative impact on the development of quantitative sustainable consumption research, leading to a slower process for theory development and weaker policy

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[1] The policy package "Fit-for-55" proposed by the European Union is a notable exception to this, as it would explicitly connect supply and demand side changes. If technological development and energy-efficiency improvements cannot achieve sufficient mitigation, prices will increase and drive the necessary changes in consumption. Also, the recently proposed target for consumption-based emissions in Sweden could pave the way for explicit demand-side policies where technological solutions are not deemed sufficient. However, at the time of writing, none of these have been adopted.

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recommendations. Building on previous work by Andersson (2020), for the first time, in this paper we use individuals' transaction data from their bank(s) paired with environmentally extended input–output data to provide a detailed account of individuals' consumption and its interrelated emissions.

The aim of this paper is to provide a first attempt at estimating the entire carbon footprint of individuals based on financial transaction data, and to evaluate the direct and indirect effects of four low-carbon lifestyle options: not owning a car, not flying, not living in a detached house, and having a vegan diet, in a sample of environmentally concerned individuals. To the best of our knowledge, empirically based estimates of these effects have not been made and this analysis therefore provides a starting point for further enquiry (Reimers et al., 2021).

There are at least three potentially important factors that may affect the net effect of different low-carbon behaviours: (1) financially driven rebound effects that counteract the initial reduction in carbon footprint through redirected spending in other consumption domains with their related emissions; (2) psychologically motivated spillover effects whereby a pro-environmental behaviour in one consumption domain may lead either to further efforts to avoid carbon-intensive behaviours in other domains i.e., positive spillover effects; or alternatively that the initial pro-environmental behaviour leads to an increase in consumption in another domain, i.e., a negative spillover effect. In addition, (3) different behaviours may be interlinked so that one behaviour implies another behaviour, such as living in a detached house that is typically situated outside the city centre also entails owning a car (or two). By empirically analysing the indirect effects for individuals who are already implementing a low-carbon behaviour, we were also able to shed some light on the relative importance of these theoretical perspectives (Reimers et al., 2021).

This paper is structured as follows: Section 2 presents three theories that could explain the mechanisms of indirect effects; Section 3 describes the data collection and recruitment process using a carbon calculator; Section 4 presents the empirical results from the quantitative analysis; Section 5 places our findings in a larger context and discusses the opportunities and drawbacks of using transaction data, and finally Section 6 concludes.

2. Theory

This paper does not attempt to explain why our sample of respondents have implemented their current low-carbon lifestyle options; instead we are interested in estimating the indirect effects of these and to understand the underlying mechanisms. In this section we describe three theoretical concepts that can be used to explain such indirect effects: rebound effects, spillover effects and what we term 'interrelated practices', and examine how they may explain these indirect effects and predict their size and direction (negative or positive) with regards to carbon footprint.

The economically induced *rebound effect* involves different mechanisms that reduce expected CO_2eq savings from energy-efficiency measures, new technologies or sufficiency strategies, because people respond to the relative changes in their costs and disposable income by redirecting their spending towards goods and services that have become relatively cheaper. There are two mechanisms at work here: the price effect and the income effect. The price effect refers to increased consumption of a good or service due to a lower cost of using the good or the service. A typical example is the increase in driving distance after switching to a fuel-efficient car, due to a lower operating cost per kilometre (Sorrell et al., 2009). The income effect, on the other hand, refers to the effects of re-directing savings generated by the lower cost of a good or using a service. For example, the money saved by switching to a fuel-efficient car may instead be spent on holidays or shopping.

Indirect rebound effects can also be caused by sufficiency actions, whereby savings associated with reduced consumption of goods and services in one domain can lead to increased spending and emissions in other domains (Sorrell et al., 2018). A few studies have estimated the size of indirect rebound effects from sufficiency actions on household consumption and we will briefly describe them here, as they represent the most relevant comparison for the present study. The research in this field models different changes using household budget surveys in combination with assumptions about how the introduction of a hypothetical energy efficiency improvement or lifestyle change would affect prices, household budgets and, through assumptions regarding price and income elasticities, consumer demand and GHG emissions. The results suggest that indirect rebound effects range from 16%–200% in the area of food, 15%–83% in the area of transport, 7%–35% in the area of heating, and 4.5%–6.5% in the area of electricity (Alfredsson, 2004; Chitnis et al., 2014; Druckman et al., 2011; Lenzen and Dey, 2002; Bjelle et al., 2018; Murray, 2013).

The above research on different rebound effects may provide relevant information about how underlying societal and structural changes could alter consumer demand, but it fails to conceive of effects related to pro-environmentally motivated actions and how different lifestyles and practices may be contextually interrelated. Bjelle et al. (2018) attempted to evaluate the effect of green behaviours and estimated the effect of 34 actions that Norwegian households could take to lower their carbon footprints and compared marginal and 'green' patterns of redirected spending, where the latter involved avoiding redirecting spending on the most emissions-intensive products. Assuming the marginal redirected spending pattern, the estimated average rebound effect across all actions was 59%, while with the "green" pattern, the rebound effect was reduced to 40%. In a previous study, we also found that consumers buying a car labelled as "green" caused no significant direct rebound effects, in contrast to those who bought a fuel-efficient car without the "green" label who exhibited an expected direct rebound effect of 30% (Andersson et al., 2019). This indicates that pro-environmental motivation may mitigate rebound effects.

Psychological *spillover effects* explicitly refer to how a pro-environmental behaviour in one domain may affect and "spill over" into behaviours in other domains. Positive spillover effects reflect an increased propensity to adopt additional pro-environmental behaviours in other domains (Thøgersen, 2004; Thøgersen and Crompton, 2009). Mechanisms for positive spillover effects may be overall concern for the environment or a desire for consistency across behaviours, thus motivating pro-environmental behaviours in several domains. Negative spillover effects, on the other hand, refer to when an initial pro-environmental behaviour leads to a decreased propensity for pro-environmental behaviours in other domains. The mechanisms behind negative spillover effects are often attributed to moral licensing, meaning that a previous pro-social act makes people feel they have "done their bit" and are therefore less inclined to adopt other pro-social behaviours. The research in this area is largely inconclusive (Nilsson et al., 2017), but a recent meta-analysis suggests that negative but small spillover effects are more commonly described in the literature (Maki et al., 2019).

A third theory – practice theory – suggests that human actions should be understood in relation to their surrounding environment or system, different behaviours and the use of technologies (Wilhite, 2007). According to this theory, the actor-centric approaches underlying rebound and spillover effects that primarily understand and attempt to explain behaviours as intentional individual actions, are ultimately flawed, as they position individuals as largely rational actors, and cognitive processes as the central drivers of action (Chatterton, 2016; Shove, 2010). Instead, according to practice theory, different low-carbon behaviours cannot be properly understood if they are not analysed contextually — in order to understand their situated meanings and the interconnections between technologies and lifestyles. Given the contextual outlook of practice theory, researchers in this field have traditionally not analysed effects using quantitative methods. This

Fig. 1. Sections of the Carbon Calculator. Profile field private transport using registry number as input (left), general overview (middle), and emission estimates from individual purchases (right).

research has instead contributed a qualitative understanding of the interconnections between practices (Kent, 2022; Twine, 2017). There are, however, also examples from quantitative research of how *interrelated practices* can form indirect effects; living in a detached house often entails a lifestyle that requires owning a car, while contrary, a more urban lifestyle tend to be connected to long distance air-travel (Ottelin et al., 2014; Holz-Rau et al., 2014).

3. Materials and methods

This section describes the recruitment, selection, and surveying of the study participants, and how the participants' carbon footprints were calculated using a carbon calculator. To recruit participants, and calculate their carbon footprints, we collaborated with Svalna Inc. (www.svalna.se), a Swedish green-tech company that has developed a carbon calculator in the form of an app of the same name.

3.1. Recruitment and selection of participants

Participants were recruited via two platforms: the Svalna app, and Facebook. Approximately 7000 users of the app were invited to participate in the study. The invitation was only sent to users who had connected their internet banking to the app and stated that they were willing to share their banking data for research purposes. To increase the share of participants with the specific low-carbon behaviours, we also recruited participants by posting information about the study in six Facebook groups. We also used targeted advertisements on Facebook to recruit environmentally aware participants. People who responded to the Facebook advertisement or any of the Facebook posts were directed to the App Store or Google Play Store to download the app using 'magic links' that allowed the app to identify recruited participants in the account set-up process.

These efforts generated a total of 2005 survey-participants, of which 1644 were previous users the app (i.e., 82%). Finally, we applied a set of selection criteria that limited the final sample to 715 participants. The criterion with the biggest impact was to only include historical transaction data from before the participants downloaded the app. This decision was made because we did not want the data to be affected by feedback from within the app itself. Since banks put limits on the availability of past transaction data, this meant that the data from some long-term users of the app did not match this criterion. We also decided to exclude all transaction data dating from after the outbreak of the COVID-19 pandemic in Sweden in February 2020. A maximum of 12 months of data were used for each participant.

Given that our sample population has self-selected into a carbon calculator app, they are likely to be highly motivated towards protecting the environment. But it is important to acknowledge that these lifestyle options are not necessarily pro-environmental by intent. People may of course choose not to own a house or car, or fly, for economic or personal reasons. Moreover, people may have a vegan diet for other ideological and/or health reasons, such as protection of animal rights, rather than having an intention to reduce their emissions. Nevertheless, each of these lifestyle options leads to substantially lower GHG emissions on average.

3.2. Survey among participants

Recruited participants were asked to fill in a survey to gauge their level of environmental concern and their pro-environmental personal norms. We used a three-item question on *environmental concern* previously developed and used by the SOM (Society, Opinion and Media habits) Institute in Sweden, and asked participants to rate their level of concern about changes in the Earth's climate, the deterioration of the marine environment, and environmental degradation in general.

We also designed a battery of statements to rate the participants' *pro-environmental personal norms*: "For the sake of the climate, I feel a moral obligation to…Restrict my flying/Eat vegetarian or vegan/Consume less/Repair things instead of buying new/Choose sustainable means of transport/Limit my energy use". The participants had to rate to what extent they agreed with each statement, by choosing between 1 (completely disagree) and 7 (completely agree). The response value of the six question items was used to generate a pro-environmental personal norm score with a satisfactory level of internal consistency (Cronbach's alpha .82).

3.3. Calculation of carbon footprints using a carbon calculator

The participants' carbon footprints were calculated using the app (Fig. 1), which estimates the GHG emissions of private consumers using financial transaction data from users' bank account(s), in combination with information about their lifestyle (Andersson, 2020).[2]

By connecting their bank account(s) and/or credit cards to the app, users get an overview of their carbon footprint from their spending and lifestyle choices, divided into four main categories: residential energy use, transport, food, and miscellaneous, with 65 sub-categories. The app uses a hybrid approach that relies on data from three primary

[2] The Svalna app can be downloaded for free from the App Store/Google Play Store (currently only available in Sweden), and had approximately 19,000 users in January 2022.

Table 1
Descriptive statistics. Mean values for the individuals performing the four low-carbon lifestyle options.

Variables	Units	Full sample	No car	No flying	No house	Vegan
Total GHG emissions	tonnes CO_2eq/cap/yr	7.61	6.29	6.68	7,01	5,21
Total expenditures	kSEK/yr	295	240	280	276	220
Nr. of adults		1.80	1.68	1.80	1.67	1.78
Nr. of children		0.63	0.31	0.70	0.46	0.39
Women	%	59.2	64.1	56.7	62.1	67.5
Age	years	36.9	32.5	37.0	34.8	29.8
Large city	%	34.7	41.1	30.1	41.1	31.3
Pro-environmental norm	1–7	6.12	6.21	6.20	6.13	6.49
N		709	384	372	509	80

sources to calculate the GHG emissions associated with a user's consumption: (1) financial transaction data from the user's bank account coupled with data on GHG emissions per monetary unit for different consumption categories; (2) data from official databases such as the national motor vehicle registry; and (3) self-reported data entered by the user.

Accounts in all banks in Sweden can be connected to the app. Users who connect their bank(s) to the service automatically get a baseline reading of their spending and hence their carbon footprint for a period back in time averaging 16 months. All transactions (credit/debit card transactions, invoice payments, transfers to their own/external bank accounts, cash withdrawals, etc.) are classified according to a modified version of the Classification of Individual Consumption According to Purpose (COICOP) scheme developed by the United Nations Statistics Division. Users are asked to classify transactions that are not automatically identified by the system, which helps to improve the algorithm over time for all users of the app. The users can also indicate if a specific purchase was second-hand, in which case the app attributes lower emissions to that purchase. The GHG emissions associated with the majority of purchases are estimated as the product of the expenditure and the GHG intensity (g CO_2eq/SEK) of the associated COICOP consumption category, as estimated using environmentally extended input–output data (Tukker et al., 2009; Davis et al., 2011; Ivanova et al., 2016; Stadler et al., 2018).

4. Results

In the following sections, we will go through the descriptive statistics and then present the results of the multivariate analysis. Finally, we compare our empirical results with the result of a theoretical marginal redirection of spending effect.

4.1. Descriptive statistics of the analysed low-carbon lifestyle options

Table 1 shows the mean values of total GHG emissions, expenditure, number of adults in the household, number of children in the household, gender, age, degree of urbanity (proportion living in a large city), and the pro-environmental personal norms of those practising the four low-carbon behaviours. The average age in the full sample was 37 years, while the average age of the adult population in Sweden was 48 years. The share of women was 59%. Users were more likely to live in large cities (35% in our sample, compared to 18% in all of Sweden), and more likely to live in apartments (72% in our sample, compared to 55% in all of Sweden).[3] The mean of the pro-environmental personal norm scores for the full sample was 6.12, and the group with the highest mean value was the vegans (6.49).

Of the participants in the study, 80% stated that they were "very worried" about the Earth's climate, the deterioration of the marine environment, and environmental degradation in general, which can be compared to 50% of respondents in a large survey conducted the same year on a representative sample of the Swedish population.[4] As expected, concern about the environment in our sample is comparatively high.

Table 2
Pearson correlation coefficient matrix.

Variables	1	2	3	4	5	6	7
1. GHG Short-distance Travel	–						
2. GHG Long-distance Travel	.04	–					
3. GHG Housing	.20***	.04	–				
4. GHG Food	.30***	.08*	.20**	–			
5. GHG Miscellaneous	.26***	.14***	.28***	.33***	–		
6. GHG Total	.52***	.39***	.61***	.58***	.80***	–	
7. Pro-environmental Norm	–.07	–.07	.02	–.29***	–.06	–.14***	-

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

The average carbon footprint in the full sample was 7.6 tonnes of CO_2eq/cap/yr. This can be compared to the average carbon footprint of the adult population in Sweden, which was roughly 9.3 tonnes of CO_2eq/cap/yr, when estimated in a similar way.[5] The carbon footprint in our sample was thus 20% lower than the average, which is not surprising provided the higher proportion of people with more sustainable lifestyles, for example living in apartments and having a vegan diet, and their relatively higher level of concern for the environment. Given these factual differences and the possible effect of a high level of concern for the environment in this group, the relatively small difference in carbon footprint compared to the average population may in fact be more surprising.

As can be seen in Fig. 2, travelling accounts for 25% of the total emissions, of which around half is short-distance travel (primarily by car) and the other half is long-distance travel (primarily by air). Food accounts for 24%, housing 16%, and miscellaneous products and services 35%.

Among the four low-carbon lifestyle options, the group of vegans had the lowest overall carbon footprint (5.2 tonnes of CO_2eq/cap/yr), which was 2.4 tonnes of CO_2eq/cap/yr lower than the average in the sample, and 4 tonnes of CO_2eq/cap/yr lower than the average among adults in Sweden. Besides lower emissions from food, this group also had lower total expenditure compared to the average. People in the groups vegan, no car, and no detached house were also comparatively younger than the average.

Table 2 presents a correlation matrix that shows the linear relationship between the carbon footprints associated with different consumption domains, the total emissions, and the pro-environmental personal norm score. The pro-environmental personal norm score is negatively correlated with the individuals' total emissions, which is mainly explained by the negative correlation between the pro-environmental personal norm score and emissions from food. The negative correlation between pro-environmental personal norm and emissions from food

[3] All figures for the average Swedish population come from Statistics Sweden's Statistical Database at https://www.statistikdatabasen.scb.se/pxweb/en/ssd/, Accessed 22-03-22.

[4] SOM Miljö- och klimatopinion i Sverige 2020, Accessed 22-03-09.

[5] Based on Swedish Environmental Protection Agency, 2019, Accessed 22-03-09.

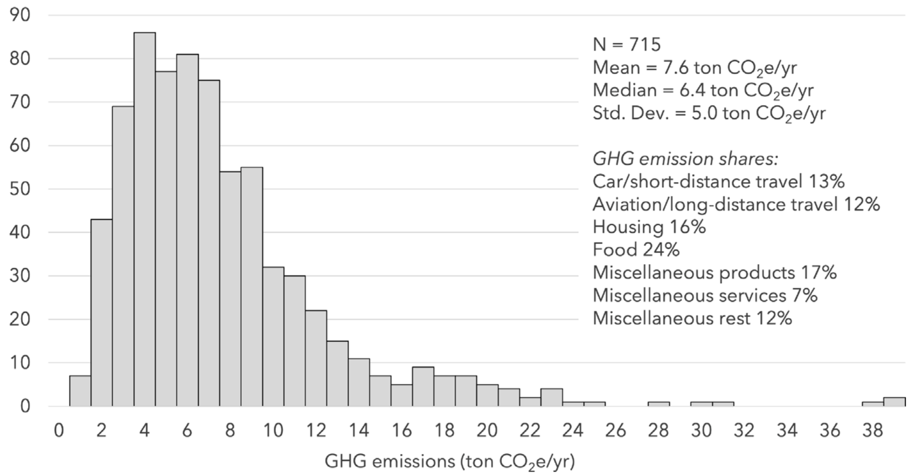

Fig. 2. Frequency plot and descriptive data on GHG emissions.

may be explained by the very strong pro-environmental personal norms among the low-emitting vegans of the sample as seen in Table 1.

4.2. Linear regressions

In order to analyse the direct and indirect effects of the low-carbon behaviours, we used multivariate linear regressions with the same set of independent variables to analyse dependent variables: GHG_{total}, GHG_{direct}, $GHG_{indirect}$ for all four lifestyle options, respectively. To control for factors that might affect the estimation of coefficients, a set of explanatory variables were included in the regression models, namely total expenditure, number of adults in the household, number of children in the household, gender, age, and type of residential area. The results of the regression analyses are presented in Table 3.

Note that, since (1) $GHG_{total} = GHG_{direct} + GHG_{indirect}$, (2) we use linear models to explain variation in GHG emissions, and (3) we use the same set of independent variables *i* in the models for GHG_{total}, GHG_{direct} and $GHG_{indirect}$, the regression coefficients B_i for each independent variable add up so that $B_{i,total} = B_{i,direct} + B_{i,indirect}$. For example, in Table 3 Short-distance Travel (SDT) shows that the regression coefficient for not owning a car as compared to owning a car is –0.466 tonnes of CO_2eq/cap/yr for GHG_{SDT} (the direct effect), –0.082 tonnes of CO_2eq/cap/yr for $GHG_{indirect}$ (the indirect effect, non-SDT), and – 0.466 – 0.082 = –0.548 tonnes of CO_2eq/cap/yr for GHG_{total} (the total effect).

In the same way, the indirect effect of an independent variable *i* may also be further subdivided into different emissions categories j (transport, housing, etc.), for which $B_{i,total} = B_{i,direct} + \sum B_{i,j}$. Hence, by analysing the indirect effects of all four low-carbon lifestyle options on the GHG emissions associated with short-distance travel, long-distance travel, housing, food, and miscellaneous, we can estimate the size and direction (positive or negative) of the indirect effects. While none of the indirect coefficients $B_{i,j}$ in the regression models are significant on their own (their variation is very large) they always add up correctly to the difference between the $B_{i,total}$ and $B_{i,direct}$ estimates.

Fig. 3 summarizes the results from the 12 multivariate analyses and provides an overview of the different direct and indirect effects of the four low-carbon lifestyle options: not owning a car, not flying, not living in a detached house, and have a vegan diet. We see, for example, that the direct effect of having a vegan diet was associated with 1.29 tonnes of CO_2eq/cap/yr less emissions from food, compared to a mixed diet. A rebound or negative spillover effect would have been expected to result in a lower reduction in total emissions, but instead we see that a vegan diet was associated with 1.55 tonnes of CO_2eq/cap/yr lower total emissions, i.e., slightly lower emissions also in the other domains. Similar patterns are found for not owning a car, and not living in a detached house, whereas not flying was associated with a minor rebound effect of 2%. Since the general relationship between the low-carbon lifestyle options and other consumption domains seems to indicate strong positive spillover effects, in the following, we will try to discern if there is reason to believe that they should be understood as such, or alternatively whether the relationships could imply effects caused by interrelated practices.

Looking at the indirect effects of not owning a car, a small positive correlation with the emissions from long-distance travel is seen, indicating, in line with previous research (Ottelin et al., 2014; Brand and Preston, 2010), that people with no car tend to fly more. Not owning a car was negatively correlated with emissions from housing, which is likely associated with the connection between living in a detached house and owning a car.

The positive correlation between not flying and emissions from housing could reflect a tendency among participants living in detached houses to go on holidays abroad less frequently, but given the non-representativity of our sample, this relationship could also be associated with the composition of the group. The lack of a negative correlation between not flying and emissions from short-distance travel is somewhat surprising, since the car could be expected to "fill the gap", by enabling holiday travelling.

For people living in apartments, as compared to detached houses, the single largest indirect effect was found in its negative correlation with emissions from miscellaneous goods and services (–253 kg CO_2eq/cap/yr).[6] The results clearly show that having a vegan diet is associated with lower emissions in all consumption domains (total indirect effect: –264 kg of CO_2eq/cap/yr). Since dietary choices are not directly linked to other lifestyle traits, and since the vegan group has high pro-environmental norms, it seems reasonable to assume that the amplified emission reductions could be interpreted as a positive spillover effect generated by the strong pro-environmental norms among vegans.

4.3. Comparison of empirical results to the marginal redirected spending assumption

We also compared our results of indirect effects to the hypothetical indirect rebound effect, calculated based on the marginal redirected spending assumption (MRA) (see for example (Bjelle et al., 2018; Grabs,

[6] The correspondingly higher emissions related to living in a separate house cannot be explained by increased consumption of furniture, home decorations or consumption related to gardening, since these emissions are attributed to the housing domain, not miscellaneous.

Table 3
Linear regressions of the greenhouse gas emissions associated with short-distance travel, long-distance travel, food and housing. Unstandardized regression coefficients (standard errors in parenthesis).

	GHG: Short-distance travel			GHG: Long-distance travel			GHG: Housing			GHG: Food		
	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total	Direct	Indirect	Total
No car	−.466***	−.082	−.548*									
	(.085)	(.211)	(.221)									
No flying				−1.52***	.023	−1.50***						
				(.085)	(.207)	(.226)						
No house							−.566**	−.214	−.780*			
							(.205)	(.262)	(.303)			
Vegan										−1.29***	−.264	−1.55***
										(.079)	(.268)	(.277)
Vegetarian										−.904***	−.148	−1.05***
										(.080)	(.222)	(.239)
Pescetarian										−.859***	−.186	−1.05***
										(.096)	(.299)	(.314)
Tot. Exp. (100 kSEK/yr)	.144***	1.63***	1.77***	.100***	1.66***	1.76***	.364***	1.42***	1.78***	.178***	1.59***	1.77***
	(.030)	(.128)	(.142)	(.030)	(.132)	(.141)	(.088)	(.122)	(.141)	(.034)	(.128)	(.140)
Nr. of adults	−.024	−.060	−.084	.056	−.134	−.078	−.172**	.026	−.146	−.029	−.013	−.042
	(.040)	(.101)	(.117)	(.040)	(.096)	(.108)	(.061)	(.118)	(.128)	(.035)	(.102)	(.112)
Nr. of children	−.017	.209	.192	−.039	.373**	.334**	.032	.173	.205	.119*	.088	.207
	(.048)	(.121)	(.131)	(.048)	(.118)	(.123)	(.066)	(.114)	(.126)	(.051)	(.111)	(.122)
Sex (man, ref. woman)	.237**	−.365	−.128	−.084	.092	.008	−.103	−.041	−.144	.040	−.197	−.156
	(.092)	(.220)	(.244)	(.092)	(.225)	(.239)	(.136)	(.219)	(0.240)	(.090)	(.216)	(.238)
Age 18–29 (Ref. 45–64)	.133	−.479	−.346	.031	−.615	−.585	.005	−.346	−.341	−.091	−.115	−.206
	(.130)	(.352)	(.391)	(.130)	(.328)	(.363)	(.223)	(.343)	(.386)	(.145)	(.319)	(.365)
Age 30–44 (Ref. 45–64)	.253*	−.613	−.360	.130	−.557	−.427	.071	−.385	−.314	−.243	.033	−.210
	(.120)	(.322)	(.356)	(.120)	(.321)	(.341)	(.201)	(.324)	(.352)	(.134)	(.301)	(.336)
Age 65– (Ref. 45–64)	.481	.121	.602	−.146	.692	.546	.135	.563	.699	.316	.286	.602
	(.418)	(.709)	(.894)	(.418)	(.845)	(.927)	(.462)	(.793)	(.883)	(.372)	(.752)	(.910)
Large city (Ref. rural)	−.326	−.009	−.335	.282*	−1.03**	−.751*	.370	−.577	−.207	−.223	−.189	−.412
	(.167)	(.352)	(.386)	(.167)	(.323)	(.366)	(.224)	(.398)	(.411)	(.218)	(.293)	(.375)
Commuter town (Ref. rural)	.026	.202	.228	.141	−.234	−.093	.334	−.074	.260	−.025	.180	.155
	(.204)	(.453)	(.517)	(.204)	(.459)	(.504)	(.255)	(.483)	(.519)	(.247)	(.408)	(.502)
Med. sized town (Ref. rural)	−.290	.099	−.191	.302*	−.63	−.328	.720***	−.804*	−.084	−.340	.059	−.280
	(.174)	(.355)	(.397)	(.174)	(.335)	(.376)	(.188)	(.396)	(.404)	(.218)	(.296)	(.380)
N	709	709	709	709	709	709	709	709	709	709	709	709
Adj. R^2	.201	.674	.683	.335	.712	.703	.241	.628	.685	.364	.665	.693

***$p < 0.001$, **$p < 0.01$, *$p < 0.05$.

2015)). The MRA, as we define it here, means that all possible savings from a "green behaviour" or low-carbon consumption behaviour are instead spent on other goods and services at the marginal GHG intensity, estimated from cross-sectional comparisons of consumers.

Table 4 summarizes the four low-carbon lifestyle options and their effects on direct spending, along with the marginal GHG intensity (e.g., for 'vegan' this represents how much their GHG emissions increase with expenditure on all other categories except food), the resulting indirect effect from multiplying these numbers, and finally the corresponding measured indirect effect as previously presented in Fig. 3.

Two of the lifestyle options – not owning a car and not flying – were associated with reduced direct spending in the categories short-distance travel and long-distance travel, respectively. Based on the MRA, these two were expected to lead to rebound effects of 22% and 8%, whereas the actual outcome was measured as –18% and 2%.

A vegan diet was associated with almost identical spending on food as a mixed diet (see Table 4), hence no redirected spending effect is anticipated. Table 4 also shows that participants living in a detached house had lower spending on housing compared to participants living in an apartment. This may seem surprising, but we believe that this is because people living in detached houses often have an advantageous position in the housing market, due to old investments in houses from decades back when housing prices where a fraction of current prices. Hence, this estimate is not representative for people who move from an apartment to buying a house today, which would most likely be associated with increased expenditure on housing. In all four cases, the measured indirect effects lean towards lower rebound effects or larger positive spillover effects than what would have been expected based on the MRA.

5. Discussion

This study set out to test the use of transaction data from the participants' bank accounts to analyse consumer behaviour and interrelated GHG emissions. This approach was applied to an empirical analysis of the direct and indirect effects of four low-carbon lifestyle options. In the following, we discuss the methodological contribution of this study and its empirical findings.

5.1. Methodology

The analyses conducted in this paper provide a first attempt to use transaction data to analyse consumer behaviours, and we believe our results prove the potential of use this data to understand direct and indirect effects of different consumption behaviours. We see several benefits of using this approach in a wider context of sustainable consumption research and for that matter, other research studying human behaviours, and in the following we will go through some benefits and drawbacks.

The underlying data is elaborate and provides opportunities to conduct further analysis to study detailed relationships between consumption in different domains, examine and infer causal events, study the relationship between cultural, social and mental differences and consumption behaviours in detail. We believe this approach could

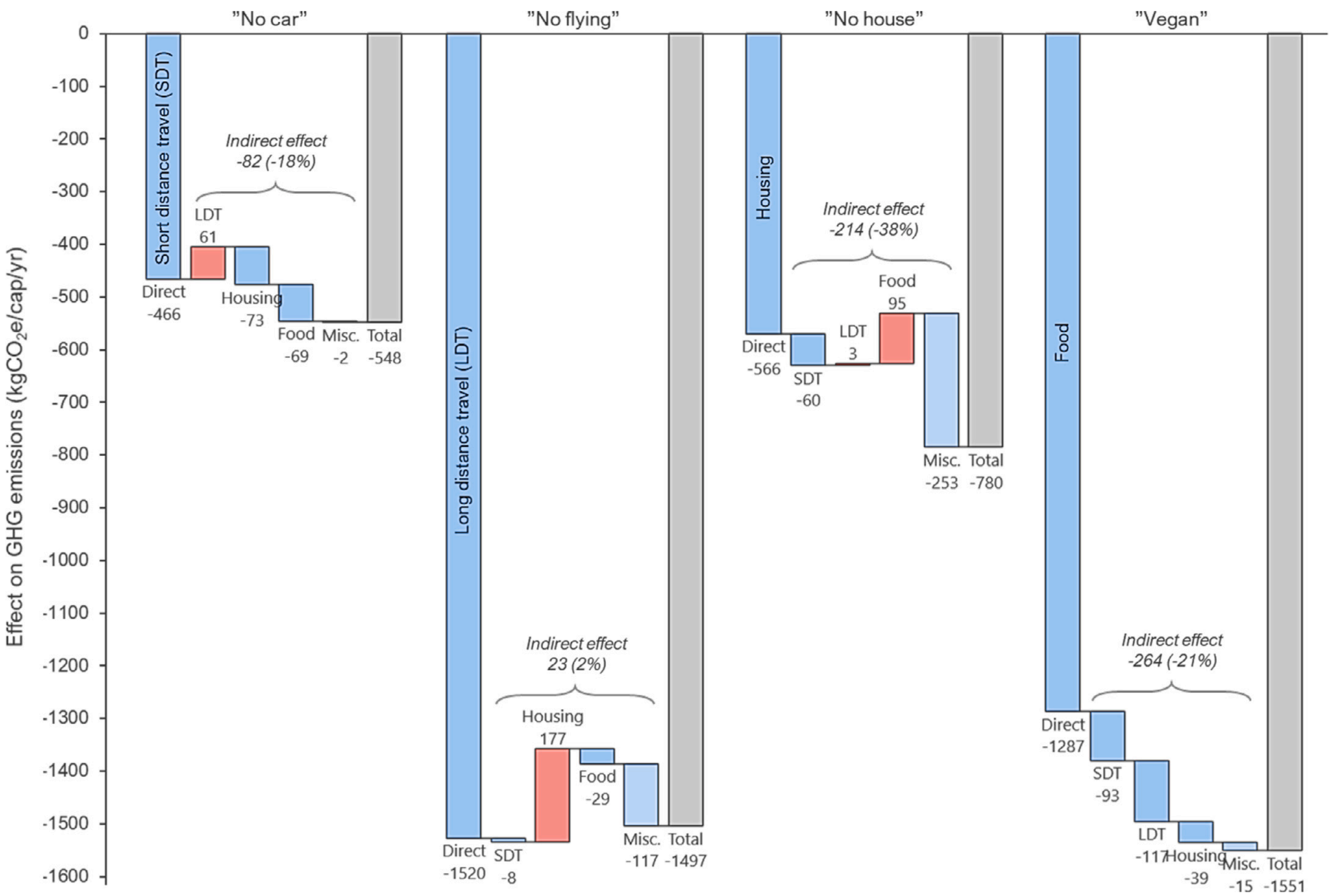

Fig. 3. Direct, indirect and total effects on greenhouse gas emissions associated with four low-carbon lifestyle options.

Table 4
Comparison between the measured indirect effects and hypothetical indirect effects following the marginal redirected spending assumption (MRA).

	Direct spending SEK/yr	Indirect spending SEK/yr	Marginal GHG intensity gCO2e/SEK	Indirect effect MRA kgCO2e/yr (%)	Indirect effect measured kgCO2e/yr (%)
No car	−6152	6152	17.0	105 (22%)	−82 (−18%)
No flying	−6600	6600	17.8	118 (8%)	23 (2%)
No house	10690	−10690	18.3	−196 (−35%)	−213 (−38%)
Vegan	184	−184	18.0	−3 (−0%)	−264 (−21%)

provide the means to verify or falsify many issues within the field of sustainable consumption.

Collecting data from participants this way provides detailed carbon footprint estimates for up to 4 years prior to current date. This provides a stable basis for analysis that captures both everyday consumption behaviours and more infrequent purchases that may have a large impact on the total carbon footprint, such as air-travel. The long baseline of historical consumption also opens up for recruitment and analysis of identified groups of individuals that have previously realized a change, such as reduction in work-time, change to an electric vehicle et cetera, to see how that change affected overall consumption patterns and interrelated GHG emissions.[7]

There are, however, also several limitations related to the use of transaction data. For an initial analysis, the type of sample used in this paper was useful since we could target relatively large groups of 'green' consumers, for example, as many as 80 vegans, which is extremely rare in representative samples such as the national dietary survey. But the recruitment of a more representative sample population, which would also permit more generalizable conclusions, is likely to prove challenging since people may be deterred from participating if it requires connecting an app to their bank and sharing information about individual purchases.

Another weakness related to opportunities to collect representative data is the obstacle of collecting data on the spending from entire households. For the purposes of this study, data on individuals' consumption behaviour and their estimated carbon footprint was deemed sufficient, but most research that studies consumption would benefit from consumption data at the household level. This limitation could probably be mediated by using data from shared bank accounts for multi-person households with the same bank, since all accounts on the users bank are also automatically connected to the app.

Regarding the quality of the carbon footprint estimates per se, using category-specific GHG emissions intensities from multi-regional input–output databases currently constitutes the preferred approach

[7] The opportunity to design different experimental "treatments" is also a promising path explored in Enlund et al. (submitted for publication).

to estimating and comparing the total carbon footprints of private consumers (Tukker et al., 2018). However, using GHG emissions intensities that represent broad consumption categories inevitably risks deviating from what could be considered the most accurate estimate for certain goods and products (Steubing et al., 2022). For most research purposes, this would not be a large problem, provided that errors are evenly distributed in the study population. But research suggests that high-income earners who tend to buy more expensive products and services will in effect be "punished" by this approach, since their carbon footprints might be overestimated (Girod and De Haan, 2010).

Moreover, there is also a risk that the transaction data may be erroneously categorized by the system, or that user re-categorizations reinforce errors in the database, and hence generate false emissions estimates (see Andersson, 2020 for a discussion on this). Such technical problems can however be overcome by stringent procedures.

5.2. *Empirical findings*

In a nutshell, our work suggests that environmentally motivated people tend to avoid altogether the economically induced rebound effects and the psychologically motivated negative spillover effects of redirected spending, and instead act in line with what is best described as an overarching motivation to reduce their climate impact. The lack of previous empirical studies on such sufficiency rebound effects, i.e., the net effect of pro-environmentally motivated actions, and the fact that our results are contrary to previous model-based research, is interesting and will hopefully lead to further research in this field.

That said, the evident weakness of our work is the fact that we cannot extrapolate conclusions from these findings to the general population, and we believe it is worth stressing just how non-representative this sample really is. Our participants are more environmentally aware than the general population, and many of them have already implemented at least one low-carbon behaviour in their lives, be it for environmental reasons or not. Also, given that most participants self-selected to use a carbon calculator app, they are likely to be at least curious about ways to reduce their carbon footprint. Taken together, this means that our sample may be very motivated to avoid rebound effects or negative spillover effects of redirecting their spending, and are more likely to exhibit positive spillover effects and avoid high-emitting behaviours. Future research conducting similar analyses of a more representative sample population would provide valuable insights into the variation in specific low-carbon lifestyles and indirect effects, with respect to both pro-environmental individuals and the general public.

This paper has shown that the indirect effects, often labelled as indirect rebound effects, are in fact negative and seem to increase net emission reductions among a sample of pro-environmentally aware people. It remains to be explored how much this sample differs from the general population, but our results seem to suggest that a more environmentally aware population in general would mean a reduction in the risks of negative indirect effects from low-carbon lifestyles. Research that has tried to analyse the relationship between pro-environmental personal attitudes, values and norms on the one hand, and households' overall carbon footprints on the other, have often found only weak support for this relationship (Nässén et al., 2015), which is not to say that these motivations are not important, but individuals' carbon footprints are also affected by income levels, socio-geographical factors that require certain lifestyles, habits and lifestyles acquired earlier in life, etc.

6. Conclusion

In this paper, we present a joint empirical analysis of the direct and indirect effects on emissions of four low-carbon lifestyle options using a sample of environmentally concerned individuals and evaluate how our empirical results stack up in relation to different explanatory theories. The direct effects are related to substantial reductions in individuals' carbon footprints, ranging from 0.5 to 1.5 tonnes of CO_2eq/cap/yr each for the different options. When also analysing the indirect effects of these lifestyle options in other consumption domains, the emissions reductions tend to increase, except for not flying, where we see a limited rebound effect. Hence, our results do not support previous research suggesting negative spillover effects or indirect rebound effects. When we compare our empirical results with the hypothetical outcome of redirecting saved expenditure to other goods and services according to the marginal redirected spending assumption, as proposed by theory, the empirical results point towards more environmentally benign indirect effects for all four of the analysed low-carbon lifestyle options.

This work also represents a first attempt to evaluate the use of financial transaction data to empirically estimate individuals' low-carbon behaviours and their interrelated emissions, with the purpose of outlining a future empirically-based approach that can accommodate and evaluate different theoretical perspectives and their merits and demerits. We believe that this approach may offer new avenues for research that may help address many open issues in contemporary research on sustainable consumption and bring about a better informed research agenda. The main limitation of the current work is the limited generalizability of results beyond a narrow group of individuals with a strong pro-environmental personal norm. Hence, an important area for future research is to find ways to recruit more representative samples.

CRediT authorship contribution statement

David Andersson: Investigation, Conceptualization, Writing – original draft. **Jonas Nässén:** Methodology, Data curation, Visualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: David Andersson reports a relationship with Svalna inc. that includes: board membership and equity or stocks.

Data availability

Data will be made available on request.

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