Journal of Cleaner Production 256 (2020) 120396

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

A novel approach to calculate individuals' carbon footprints using financial transaction data – App development and design

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ARTICLE INFO

Article history:
Received 27 August 2019
Received in revised form
4 January 2020
Accepted 2 February 2020
Available online 3 February 2020

Handling editor is Zhifu Mi

Keywords:
Carbon footprint
Carbon calculator
Calculation principles
Transaction data
PSD2
EE-MRIO

ABSTRACT

Carbon calculators can potentially help people understand and reduce their climate impact. This paper describes the features of Svalna, a mobile application that estimates users' greenhouse gas emissions by means of a hybrid approach that relies on financial transaction data from the users' bank paired with environmentally extended input output analysis; data from official registers of governmental agencies, and data entered by the users themselves. Applying financial transaction data in carbon calculators is increasingly popular, and I discuss the benefits and drawbacks of using such data in order to estimate greenhouse gas emissions. The paper also describes how design features have been developed based on insights from behavioral science and previous research on carbon calculators. The mobile application is available for use in Sweden and had approximately 15,000 users in December 2019.

1. Introduction

Climate change poses a serious threat to ecosystems and the future well-being of humanity (IPCC, 2018). In order to meet the required reductions of greenhouse gas (GHG) emissions, changes towards a low carbon culture is increasingly recognized as an important part of climate change mitigation (Edenhofer et al., 2014). The increased involvement in climate change mitigation seen around the world today, especially among young people, pose an opportunity for bottom-up political pressure that also emphasizes changing lifestyles. There is also an increasing awareness among the public of the need for lifestyle changes to mitigate GHG emissions (Von Borgstede et al., 2013).

In this context, carbon calculators can be seen as a potential bridge that connects individual action and lifestyle choices with the urgent need to counteract the worst effects of climate change. Carbon calculators could also serve the purpose to explain, from an outlook of individual carbon footprint, the societal transformation needed. Meanwhile, carbon calculators have also been accused of focusing too much on information as a means to change behavior (Spaargaren, 2011), making individuals, instead of societal bodies, the principal agent responsible for stopping climate change (Shove et al., 2012). Empirical research on the effectiveness of carbon calculators show mixed results, with some studies reporting actual reductions (Aichholzer et al., 2012; West et al., 2016), while others find no support for behavioral change (Büchs et al., 2018). Recent work also suggests that carbon calculators often fail to engage users on a regular and long-term basis (Salo et al., 2019).

This paper aims to describe the methodological framework and design features of Svalna, a novel carbon calculator available for use in Sweden. Svalna's response to the above-mentioned criticism lies in the system design: by allowing users to connect their bank and use actual spendings to calculate GHG emissions, Svalna's estimates are expected to be, and be perceived as, more accurate than those of other calculators. Continuously updated data further means that users directly can see the effects of lifestyle changes, which is believed to increase interest over time. Svalna also applies findings from behavioral research in order to engage users beyond mere information provisioning, for example by catering both to the pre-motivated users' interest in tracking their carbon footprint, and the interest seen from groups of people to learn more about their carbon footprint and try to reduce it together in groups. Besides providing end users with correct estimates of their carbon footprints, Svalna has also been developed with the aim of providing researchers with reliable and detailed data that can be used to

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https://doi.org/10.1016/j.jclepro.2020.120396

better understand a variety of issues related to sustainable consumption and production.

Svalna is currently the only carbon calculator in the world that applies transaction data to calculate users GHG emissions. At the end of 2019, several similar solutions are however being developed, such as Doconomy in Sweden, www.doconomy.com, My Carbon Action in Finland, https://enfuce.com, and Joro in the U.S., https://joro.tech/. Nordea, one of the largest banks in Scandinavia, is also releasing a simplified calculator that uses transaction data (Nordea, 2019).

The use of actual financial transaction data to estimate an individual's carbon footprint thus represents a new and interesting approach that merits further consideration. This approach has, to my knowledge, not yet been described in the research literature. In the discussion section, I will provide an account of the benefits and drawbacks of this approach, and outline some possible future methodological improvements.

2. Background

Carbon (footprint) calculators can be seen as a kind of eco-feedback technology that helps people understand their impact on the environment. By feeding a calculator with data about lifestyle and living conditions, users can get an estimate of their entire carbon footprint including direct and indirect GHG emissions. There are many carbon calculators publicly available today, developed for research, business or non-profit purposes (Mulrow et al., 2019; Birnik, 2013; Salo et al., 2019).

Notable examples that target a global audience include the Footprint calculator of the Global Footprint Network (https://www.footprintcalculator.org), WWF's climate calculator (http://www.climatecalculator.net/), the CoolClimate calculator of the University of California (https://coolclimate.berkeley.edu/calculator), and the carbon footprint calculator of the United Nations (https://offset.climateneutralnow.org/footprintcalc). While these carbon calculators primarily aim to increase the users knowledge about his/her emissions, other calculators, such as those of the MyClimate foundation (https://co2.myclimate.org) and ClimateCare (https://climatecare.org/calculator/), primarily aim to help users offset their emissions by investing in carbon compensation projects.

In addition, there are several carbon calculators that have been specifically developed for the living conditions in specific countries. Scandinavia hosts several different examples of carbon calculators including Ducky in Norway (https://footprint.ducky.eco/), Tomorrow in Denmark (https://www.tmrow.com/) Sitra's Finnish lifestyle test (https://lifestyletest.sitra.fi/), and Deedster in Sweden (https://www.deedster.com/).

3. Estimating GHG emissions at the individual level

Svalna (meaning "to cool down", in Swedish) has been developed based on the guiding principle of simplifying and automating every aspect of data collection without compromising the quality of the data. The service apply a novel hybrid approach that relies on data from three primary sources in order to estimate a user's carbon footprint: 1) financial transaction data from the user's bank paired with Multi Regional Environmental Extended Input Output data (MREE-IOA) for Swedish conditions, 2) data from official registers of government agencies, and 3) data entered by the user, see Fig. 1.

There is no established standard or consensus regarding how personal carbon footprints should be calculated (Wiedmann and Minx, 2008). Birnik (2013) has however developed a set of assessment criteria for online carbon calculators, which are used as a benchmark comparison to Svalna's model at the end of Section 3.

Svalna allows the user to connect his/her private bank accounts and credit cards to the tool. By doing so, Svalna can estimate GHG emissions from spending's within different consumption categories. All data communication is encrypted, and data are stored on secure servers in accordance with Swedish and EU regulations (GDPR). Data collection from banks is enabled via Swedish e-ID provider "Bank ID"; an electronic identification solution that allows individuals to authenticate and conclude agreements with, e.g., companies and governments agencies, over the Internet (www.bankid.com). Similar citizen identification solutions exist in most European countries and the Payment Service Directive 2 of the European Union (2015/2366) requires that all financial institutions operating within the EU facilitate for their customers to be able to share data with third parties such as Svalna. Svalna's technical solution is hence scalable to other countries in the EU.

Financial transaction data provide a detailed account of a user's expenditures. All transactions are classified according to a modified version of the Classification of Individual Consumption According to Purpose (COICOP) scheme developed by the UN statistics division (UN DESA, 2018). Users are asked to classify transactions that are not automatically identified by the system. User-classified transactions add intelligence to the system's classification algorithm, in the sense that future purchases by other users can be better pre-classified. Users can also re-classify or remove transactions that are not considered relevant.

Transaction data are available for between three months and five years back in time, depending on the bank. This means users can see how their carbon footprint has changed over time already at the first login. For research purposes, this also provides a baseline estimate of the users carbon footprint before they started using Svalna. Bank data can be updated every time the user logs in to Svalna, and in the near future the user will be able to authorize Svalna to fetch the bank data in the background for an extended period, so that emission results can be updated automatically.

Svalna includes emissions of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) using the conversion factors GWP100. Other greenhouse gases, such as water vapor and fluorinated gases, are included when considered relevant (also assessed using GWP100).

In all cases where it is considered appropriate, the GHG emissions associated with a specific purchase are calculated as the product of the expenditure amount in Swedish *kronor* (SEK), and the GHG intensity (g CO_2e/SEK) of the associated COICOP-consumption category; see Table 1 for two examples. All COICOP categories are associated with a GHG intensity that specifies the average amount of GHG emissions per monetary unit.

GHG intensities that Svalna use have been calculated by Statistics Sweden through the use of MREE-IOA data that cover the indirect supply-chain emissions from various sectors (Statistics Sweden, 2019). Statistics Sweden have calculated the GHG intensities by combining data on material footprints and monetary data on trade between sectors. Material footprints of traded goods comprise direct and indirect material inputs required for production along the entire supply chain. The total material footprint is the sum of the material footprint for biomass, fossil fuels, metal ores and non-metal ores (Wiedmann. 2009, Wiedmann et al. 2015). In order to allocate domestic extraction to exported goods, information regarding both production and the trade structure of an economy is required. In monetary terms, information on the production structure is contained in commonly available economy-wide input-output tables. In Sweden, such tables are based on Structural Business Statistics on Swedish companies paired with trade statistics from a multi-regional Input-Output database (Exiobase version 3.7, https://www.exiobase.eu/), see Tukker and Dietzenbacher, (2013) and Stadler et al. (2018).

Of course, Svalna does not know exactly what goods and services the user has consumed, only the financial expenditures in

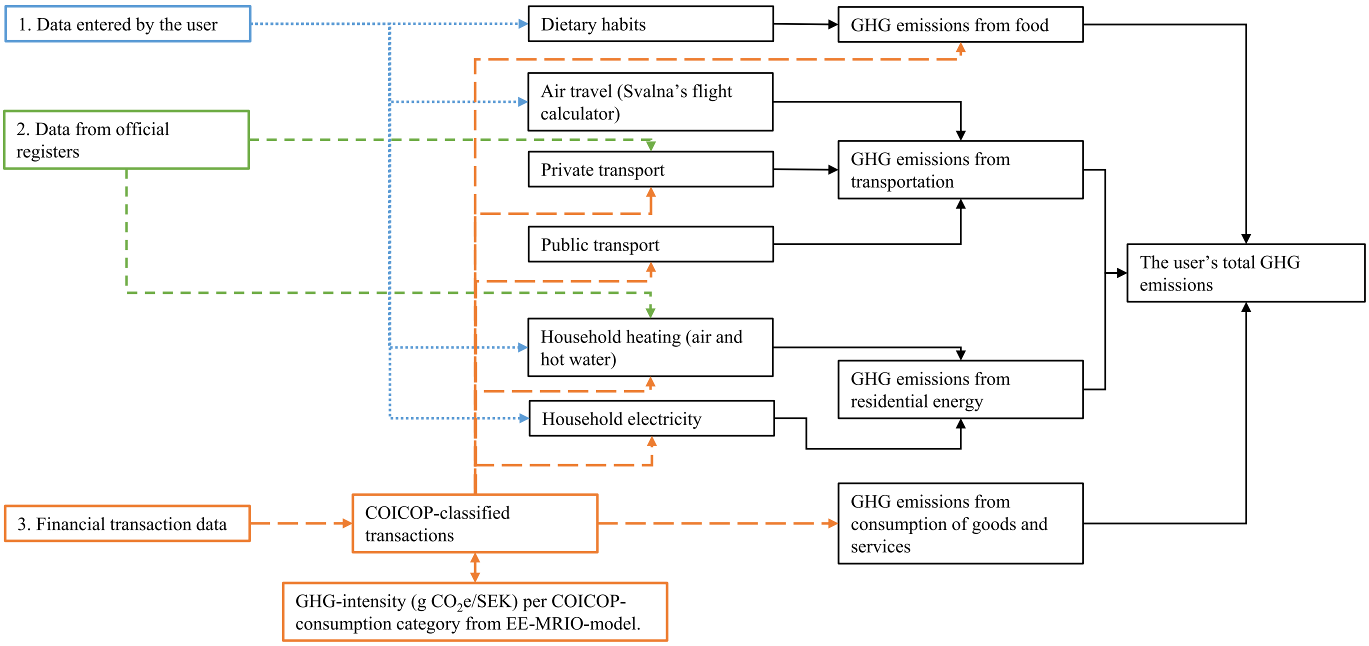

Fig. 1. Schematic overview of how Svalna combines data from various sources in order to estimate GHG emissions at the individual level.

Table 1
Two examples of how GHG emissions from consumption of goods and services are calculated as the product of the expenditure amount (SEK) and GHG intensity (g CO_2e/SEK) of the associated COICOP category. COICOP = Classification of Individual Consumption According to Purpose; CO_2e = Carbon dioxide equivalents.

Description as in the bank statement	Expenditure amount as in the bank statement (SEK)	Identified COICOP category	GHG intensity of the COICOP category (g CO_2e/SEK)	Estimated GHG emissions (kg CO_2e)
McDonald's	75	"restaurant"	30[a]	2.3
Shell	600	"fuel"	198[b]	119

[a] This number represents the GHG emissions from the restaurant sector including upstream GHG emissions from food production, and emissions caused by heating and electricity use, buildings, maintenance and furnishings, etc.
[b] This number represents the GHG emissions from upstream extraction, refining and transportation and the direct emissions from fuel combustion. As described in Section 3.2, the user can also provide the system with specific information on which fuel he/she uses, in which case a more precise emission estimate is made. Data on fuel prices are continually collected and used.

broad categories. Those expenditures are for the time being considered acceptable proxies for actual consumption.

The GHG emissions calculated by Svalna are divided into four main categories: 1) consumption of goods and services, 2) transportation, 3) residential energy, and 4) food & beverages. Sections 3.1 - 3.4 provide a detailed description of how Svalna calculates the GHG emissions in each of these categories.

3.1. GHG emissions from consumption of goods and services

The GHG emissions from consumption of goods and services are calculated using transaction data coupled with average GHG intensities per monetary unit from Statistics Sweden (2019), as described in the beginning of Section 3. Purchases of second-hand goods from retailers can be "tagged" as such by the user in order to reduce GHG emissions accordingly. Users living in multi-person households with shared economy can choose to split expenditures (and hence GHG emissions) from shared accounts, and for certain transactions alike.

3.2. GHG emissions from transportation

This category includes emissions from private and public transport, including air travel.

3.2.1. Emissions from private and public transport

The GHG emissions from private road transport (cars, motorbikes) are calculated using financial transaction data on expenditures in gas stations, together with data on monthly updated fuel prices for gasoline, diesel and ethanol (SPBI, 2018) and well-to-wheel GHG emission factors (g CO_2e/litre) for different fuels (Ahlvik and Eriksson, 2012; Swedish Energy Agency, 2013a,b, 2014a,b; Swedish Energy Agency, 2015a,b,c,e; Swedish Energy Agency, 2019; Gode et al., 2011; NTM, 2015; Swedish Transport Agency, 2015).

Users can also choose to fill in their vehicle's registration number, in which case the system automatically collects data from the Swedish Transport Agency (2019) on fuel type, fuel efficiency (litre/km as reported in the Worldwide Harmonized Light Vehicle Test Procedure (WLTP)), and distance travelled between the last two vehicle inspections (where odometer readings are noted). These data are used to improve the GHG estimates based on the financial transaction data, and support improved GHG emission saving estimates as associated with different actions suggested by the Svalna system (see Section 4.5.1).

The GHG emissions from public transport are calculated using financial transaction data coupled with average GHG intensities per monetary unit from Statistics Sweden (2019).

3.2.2. Emissions from air travel

The GHG emissions from air travel are calculated using Svalna's own flight calculator, coupled with data collected from the user on all private flights during the last two years, or transaction data dating further back in time. Users are asked to report all flights associated with financial transactions classified as "air travel" or "package holiday", by filling in departure and destination, and if the flight was a one-way or return flight. Only private flights are included in order to avoid double counting, as work-related flights and associated emissions are allocated to products/services produced by the employer.

Svalna's flight calculator estimates GHG emissions using range-based fuel consumption averages for aircraft operating on different distances. The flight distance is estimated as the greater circle distance between the departure and destination, plus a detour factor to capture the fact that the flight routes do not follow the closest range, and an approach factor to encompass that planes often cannot land directly but need to circle above the airport. GHG emissions from fuel consumption are based on well-to-wheel estimates, while GHG emissions associated with the production of aircraft and airport infrastructure are not included.

The additional warming effect of contrails that occur at high altitudes (above 8 km on average) is gradually (linearly) introduced for flights between 500 and 1000 km, since shorter flights typically remain on lower altitudes. To estimate the average warming effect of non-CO_2 emissions, e.g., contrail formation, Svalna uses an estimate from Lee et al. (2010) that adds an additional 90% to the CO_2 emissions calculated using GWP100.

3.3. GHG emissions from residential energy and construction/maintenance

Residential energy includes household electricity, heating and use of hot water. The GHG emissions from residential energy are calculated using financial transaction data coupled with data entered by the user. Users are asked about their primary source of heating and can choose between district heating, electricity, heat pump, geothermal heat pump, wood pellets, wood and oil furnace.

When the system identifies financial transaction data that are classified as any of the heat sources mentioned above, average GHG intensities per monetary unit are used to calculate the GHG emissions. Svalna has a database where monthly electricity prices are stored and used. The exception is district heating, where the regional data for emissions per energy unit are always used, regardless of the availability of transactional data.

If financial transaction data that match the user's heating source is not available, Svalna uses data on the average energy performance (kWh/m^2) of the user's apartment building in combination with the size of the residence (m^2) to calculate the residential energy demand (kWh). This is the case for a majority of apartment buildings in Sweden, since the cost for district heating is typically included in the rent, and not charged separately. The average energy performance of the user's apartment building is obtained from the National Board of Housing, Building and Planning (2019) via the user's home address. The GHG emissions from residential energy are then calculated as the product of the energy requirement of the residence (kWh) and the emission intensity (g CO_2e/kWh) of the heat source, as obtained from Swedish Energy Agency (2015d), Gode et al. (2011) and Swedenergy (2015).

Svalna takes into account that emission intensities of district heating systems vary between regions, by using "well-to-wall" emission intensities from most district heating networks in Sweden, as compiled by the Swedish District Heating Association (Swedenergy, 2019).

In order to account for GHG emissions associated with construction and maintenance of the building, Svalna adds a standard supplement of 4.8 kg CO2e/m^2/year, based on estimates from Dixit (2017). Users living in private houses are however not subject to this supplement, since they typically bear the direct costs (and hence GHG emissions) associated with construction and maintenance.

3.4. GHG emissions from food and beverages

The GHG emissions from groceries are calculated using data entered by the user, in combination with financial transaction data on expenditures in supermarkets. Payments alone are not considered to yield a sufficiently accurate estimate, given that emission intensities vary considerably depending on the user's diet and eating habits.

When setting up the account, users are requested to answer a series of questions about their diet, how much they exercise (since a higher level of physical activity implies higher energy usage), how much food they waste and in which price class they tend to buy food products. Users are then asked a series of detailed questions that vary depending on the user's diet. The diet-specific questions intend to determine the consumption level of the food items with the largest carbon footprint in each diet. Omnivores are, for example, asked how much, and what type of meat they eat, while vegetarians are asked how much cheese and dairy products they consume.

At the basis of the assessment are the carbon footprints of three different pre-defined diets as calculated by Bryngelsson et al. (2016): an average Swedish diet, a vegetarian diet and a vegan diet. Bryngelsson et al. (2016) determined the food consumption patterns in the different diets based on data from a national survey on dietary habits by The Swedish National Food Agency (2010), and trade statistics from the Swedish Board of Agriculture (2016). Bryngelsson et al. (2016) then calculated the carbon footprints of the diets using data from life cycle assessments of different food products.

Svalna uses data entered by the user to adjust the food consumption in the pre-defined diets of Bryngelsson et al. (2016). For example; all pre-defined diets are based on the same calorie intake (9,5 MJ/day of metabolizable energy). The user's self-reported physical activity level and age (when available) is then used to adjust the calorie intake up or down, based on well-established relationships between gender, age and physical activity level from the Nordic Nutrition Recommendations 2012 (Nordic Council of Ministers, 2014).

The GHG emissions from food are finally calculated by assigning the user a personalized emission intensity per monetary unit by comparing their diet and food habits to average values and scaling the emission intensity for *groceries* accordingly. Corrections are made for users for whom total expenditures in the category indicate either that they are not paying for their own groceries or that they are buying groceries for multiple household members.

3.5. Comparison with previous assessment criteria

To conclude Section 3, Svalna goes over and beyond many of the assessment criteria for online carbon calculators as described by Birnik (2013), as the service (1) estimates emissions of carbon dioxide, methane and nitrous oxide, (2) includes consumption-based GHG emissions using GWP100 conversion factors, (3) allows users to connect their bank in order to estimate GHG emissions from consumption, (4) allows users to adjust GHG estimates from e.g., housing depending on households size, (5) measures GHG emissions from heating directly through financial data and/or through data on the energy efficiency of the specific building and local district heating system, adding emissions from construction and maintenance of the building, (6) allows users to provide information on their dietary habits in order to estimate GHG emissions from food, (7) allows users to fill in air travel in order to model range-based estimates of GHG emissions also including the warming effect of contrails when appropriate.

4. User interface

This section describes the design and structure of the mobile application and the theoretical factors considered in the development. The figures depict translated versions of the appearance of the Svalna app as of the 19th of December 2019.

Svalna is structured into five sections (see Fig. 2a): *Overview, Emissions, Groups,* and *Goal*. The *Overview* section summarizes information from the other sections and gives an overview of the user's GHG emissions and trend. The *Emissions* section allows the user to explore GHG emissions over different time periods and resolutions, in order to better understand the connections between consumption and GHG emissions. The *Goal* section allows the user to set a goal, and gives the user an opportunity to experiment with different behavioral changes and investments relative to the goal. The *Groups* section allows users to engage in groups and compare themselves with others. The *Profile* section is accessed by clicking the cogwheel icon in the upper right corner. The profile allows users to manage settings in the service, e.g., with regard to the bank account and profile. The *Emissions, Groups* and *Goal* sections are intended as the primary sections of interaction and are further described in Sections 4.3, 4.4 and 4.5, respectively.

The different features included in Svalna can be linked to the most common intervention techniques described in behavioral psychology, namely information provision, goal setting, comparison, commitment, prompting, and feedback (Froehlich et al., 2010; Steg et al., 2018). By providing information about the user's carbon footprint and continuously presenting emissions from transactions, users receive feedback on their performance. The *Groups* and *Goal* sections allow users to compare themselves with others, and goal setting is possible both at an individual and group level. Feedback on the performance is also provided both to individual users and groups.

4.1. Creating an account and filling in the profile

To create an account, the user can choose to use the Swedish e-ID, e-mail or Facebook login as verification. After the account has been created, the user is prompted to fill in the user profile, which consists of a short questionnaire divided into four parts: 1) consumption of goods and services, 2) transportation, 3) residential energy, and 4) food, see Supporting Information Section SI1. The user can choose to either connect his/her bank to the app, or answer two questions about income and savings that are used to make a rough estimate on GHG emissions from consumption. The rest of the questionnaire is built as a step-by-step process containing 25 questions in which the user answers one or two questions at the time (see Appendix I for translated profile questions). Here, users can choose to share their GHG emissions with other Svalna users, and they can also choose to share their anonymised data for research purposes, which about 30% of users do. After the profile has been filled in, the user is taken to the *Overview* section.

4.2. The Overview section

The *Overview* section gives a brief glance of the user's total GHG emissions, and a breakdown between the four main categories (consumption of goods and services, transportation, residential energy, and food; see Fig. 2a). Depending on whether the user has connected the app to the bank or not, two slightly different versions of the *Overview* section is shown. If the bank is connected, the app displays trends as well as a list of the latest emissions from transactions. If the bank is not connected, the data is more static, showing only a timestamp based on the answers provided by the user when filling in the profile.

Fig. 2a. Above from left to right: Overview, Emissions and Goal sections of the app as accessed from the main menu.

4.3. The emissions section

The *Emissions* section allows users to explore how their GHG emissions from consumption vary over time and the relative size of emissions from consumption of goods and services, transportation, residential energy, and food. Users can choose to display their emissions in the perspective of one month (doughnut-chart), six months (bar-chart) or 12 months (line-chart). All charts show the composition of GHG emissions from the four main emission categories. Users can drill down to the individual transactions and their respective GHG emissions to get a more detailed understanding of which activities or transactions cause large or small emissions. Here, users can also re-categorize transactions or transfers that were not correctly classified by the algorithm.

4.4. The Groups section

The *Groups* section allows users to form, join and get engaged in groups (See Fig. 2b). By organizing themselves in groups, users can share and compare their performance with others, e.g., Facebook friends, and cooperate on common goals or compete individually or groupwise. The features of the *Groups* section intend to increase the users' motivation to reduce their emissions by evoking a sense of team spirit and/or competition.

Groups could consist of, e.g., co-workers in a workplace, students in a class, people with a shared interest, groups on social media such as Facebook, neighbors, or people living in the same municipality (all users are by default assigned to a municipality group). Groups can be either open or private, and the group administrator (the user who created the group) can set a goal for the entire group.

Different groups can be used in different ways. Municipality-based groups, for example, offer a possibility for the local environmental administration to get in touch with motivated citizens and inform them about current work and goals, and engage them in different events and activities. This approach is currently being tested by Uppsala and Jönköping municipalities in Sweden.

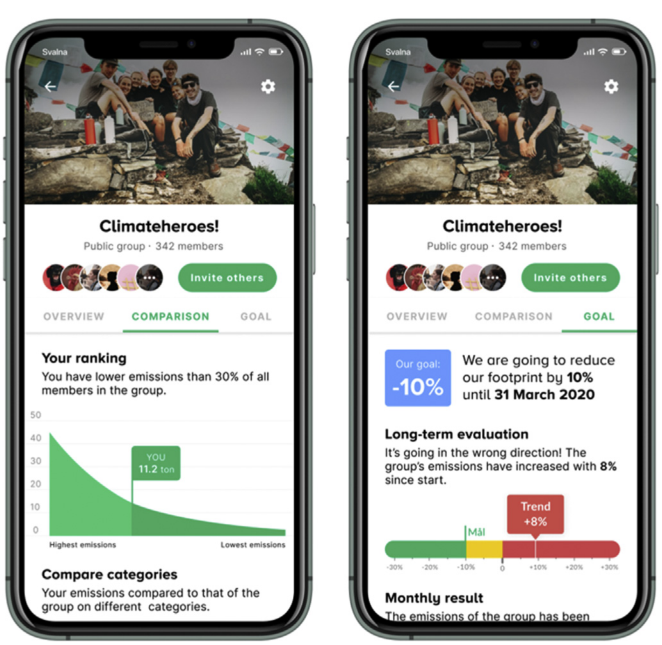

Fig. 2b. In groups, users can compare to others, set up joint goals and follow them over time.

Workplace groups can use contests, and offer a suitable platform for the company or organization to inform about their environmental and corporate social responsibility work. Household groups can be used by households and schools that arrange sustainability challenges. Research shows that campaigns directed towards young adults, and that also involve their parents, are highly effective when it comes to achieving energy savings via behavioral change and increased environmental awareness (Lawson et al., 2019).

The Groups section intends to motivate users to reduce their emissions. Research shows that several motivational processes are triggered by allowing users to compare themselves to others, either by collaborating or competing (Staats et al., 2004). The strong norms around GHG emissions and climate change are likely to form a response from users that are either above or below the average (see Cialdini et al., 1990; Cialdini and Goldstein, 2004). Comparative feedback that includes some form of social interaction has been shown to result in significant and durable behavioral change (Staats et al., 2004).

4.5. The goal section

The *Goal* section allows the user to experiment with different behavioral changes and investments in order to see how they would affect GHG emissions. The idea behind this design is that it gives users "a feel" for the magnitude of the effect of different actions, and a rough idea of what is possible to achieve. Users are expected to have a basic understanding of some climate-friendly behaviors, but few are expected to have a detailed understanding of the absolute or relative size of different behavioral changes. The *Goal* section thus also intends to increase users' carbon literacy. As can be seen in Fig. 2a, the section is organized in an upper element that shows the user's emissions and the effect of different proposed changes and investments, and a lower element that consist of a swim lane of cards that represent different changes and investments available to the user. When selecting a card, the upper element changes in order to indicate the associated emission reduction.

The *Goal* section also allows the user to set a goal for a longer time period. Since it can be tricky to set a reasonable and realistic personal abatement target, Svalna provides users with a default suggestion that can be altered in any direction. Providing a reasonable target involves different practical, political and moral trade-offs. Best estimates suggest that global GHG emissions need to decrease to net zero around 2055 in order to give us a likely chance of reaching the two-degree target, and to net zero by 2040 in order to reach the 1,5-degree target (IPCC, 2018). It further seems reasonable that rich industrialized countries should take on more ambitious abatement trajectories since this would provide some limited leeway for developing countries that may not possess the economic means to make necessary investments today. Svalna therefore uses a de-growth function that reaches one ton CO_2e by 2050 as a default.

Using a de-growth function, a user who emitted 10 ton of CO_2e in 2019 would be suggested to reduce emissions by around 7.4% per year, which corresponds to reductions of 720 kg CO_2e in 2020; 500 kg CO_2e in 2025; 300 kg CO_2e in 2030, 150 kg CO_2e in 2040, and so on. Some examples of behavioral changes or investments that could contribute to reducing emissions are: (1) shifting from an average Swedish carnivore diet to a vegetarian could reduce emissions by 1 ton of CO_2e; (2) commuting with a battery electric vehicle (BEV) instead of a small diesel car (assuming Swedish average commuting conditions, electricity mix etc.) could reduce emissions by 1.7 ton of CO_2e and (3) avoiding a two-way flight between New York and Los Angeles would mean avoided emissions by roughly 1.2 ton of CO_2e.

Setting a goal could simply inform the user of the extensive cuts in GHG emissions needed in the short term, but goal setting as a technique for behavioral change is based on the assumption that individual behavior is goal oriented and that the possibility of reaching an attractive goal could in itself motivate behavioral change (Steg et al., 2014). According to these theories, goal setting provides a source of motivation through a comparison between the present and a desirable future situation (Van Houwelingen and Van Raaij, 1989). Empirical work has also shown that goal setting increases people's focus and motivation, especially if they are about to miss their goal. Goal setting has also been shown to affect people's persistence in carrying through with certain changes (Locke and Latham, 2002).

4.5.1. User-targeted suggestions on behavioral changes and investments

In order to help users reduce their GHG emissions, suggestions on behavioral changes and investments are presented to users in the *Goal* section. Behavioral changes and investments are filtered so that only relevant suggestions are shown, i.e., suggestions that would reduce GHG emissions for this user specifically, when considering their particular economy and lifestyle. For example, "*Go vegetarian!*" is only suggested to users who are not already vegetarians or vegans. The targeting is done by filtering users using threshold conditions based on data entered by the user, and/or transaction data.

Each suggested behavioral change or investment is presented along with its user-specific emission reduction potential, calculated based on how the emission model reacts to changes in the climate profile and financial transaction data. To provide an example of how the user-specific emission reduction potential is calculated, consider the action "*Shopping-free month*". In this case, the user-specific emission reduction potential is calculated as one twelfth of the difference in modelled average yearly emissions when removing all expenditures in a selection of consumption categories (expenditures on food are, e.g., not removed).

In a future version of the mobile application, Svalna aims to add *challenges*: behavioral changes or investments that the user can choose to accept. By offering the possibility to accept challenges and get continuous interaction during the challenge and evaluation and feedback at the end, Svalna intends to create a stronger sense of commitment (as compared to the suggested behavioral change or investment described above). This feature will also give Svalna an opportunity to analyze the long-term effects of behavioral change. Such analyses are expected to provide valuable information on the stability of behavioral change and on the diffusion potential of low-carbon lifestyles and investments.

4.5.2. Feedback on user-targeted suggestions

Svalna is currently developing feedback mechanisms that will be included in a future version of the app. The idea is to provide feedback to the users who have chosen to take on one of the suggested behavioral changes or investments, in terms of GHG emission reductions. How users are to be informed about their progress is still an open issue. It may be in the form of a monthly personalized "newsletter" that describes the relevant changes, or information given in the app, depending on how frequently the app is used. The messages would typically inform users about the projected reduction and the trend so far. For example, a user that has started to ride a bike to work could receive a message saying "*Today is the 50:th day you have bicycled to work this year and you are on target for the projected emission reduction. According to our estimates, you have reduced emissions by* 200 kg *so far, which means 50% of your target for 2020 - Great work! Together with other bike converts using Svalna, you contribute to emission reductions of 20 tons* per *year.*"

In the future development of Svalna, it has been considered important to provide continuous and encouraging feedback in order to help users stay motivated and on track towards their target. Previous research has shown that frequent feedback can help people change behavior, e.g., reduce energy use (Abrahamse et al., 2005; Biel and Thøgersen, 2007; Dwyer et al., 1993). The extent of behavioral change can, however, vary greatly, as shown in an overview by Abrahamse et al. (2005) on the behavioral response from various feedback studies, where reductions in energy use, transport distance and CO_2 emissions varied between 4 and 13%, depending on the area, duration and frequency of the feedback. Salo et al. (2016) show that using tailored advice has been shown to enhance sustainable consumption, and that combining detailed advice with "intermediaries" such as municipal energy advisers, increase the number of people who change behavior.

5. Discussion

Making the data collection process as simple and straightforward as possible has been considered key in developing a user-friendly tool with high adoption potential. The use of financial transactions data to estimate GHG emissions at the individual level is novel and offers several benefits. *First*; while emissions are calculated in a rather rough manner (using broad consumption categories), the method is methodologically consistent and likely to be improved over time, and allows for robust analyses of changes over time, since consumption data are continuously updated. *Second*; the use of financial transaction data avoids uncertain self-assessed data and captures emission sources from daily consumption that are hard to capture in other ways. It would not be feasible to continuously ask users detailed questions about everything they buy, but financial transaction data provide a technically sophisticated way of capturing these purchases. *Third*; emission estimates can be generated at low effort for users, who only need to connect their bank, and fill in a short questionnaire. *Fourth*; using the user's own financial transaction data provides better opportunities for interaction and communication with the user, since users are expected to be more receptive to information that is based on their personal consumption, rather than generic statements.

Besides these benefits, the use of financial transaction data to estimate GHG emissions is also associated with some drawbacks and limitations. *First*; EE-IOA data implicitly assumes homogeneity with respect to price and product/service, while in reality the economy provides a variety of goods and services where the price is not always a good proxy for emissions. "*Clothing and shoes*", for example, is a consumption category where GHG intensities can be expected to vary considerably. An expensive designer sweater can, e.g., cost several times as much as a cheaper sweater, but cause fairly similar production-related emissions. Using price as a proxy for consumption may hence overestimate the emissions associated with purchases of expensive, high-quality products, and indirectly punishes users who invest in such products, as Girod and De Haan (2010) have shown. This is clearly an unintended side effect that might affect the overall credibility of the estimations negatively. In the future, digitally available data and improved modelling is although likely to allow access to more detailed data and estimates. Studies that have compared IO analysis and methods based on life cycle analysis seem to suggest that the truncation error in process-based LCA can be expected to be greater than the aggregation error in IO analysis (Pomponi and Lenzen, 2018; Kennelly et al., 2019). Svalna is currently developing improved emission estimates along these lines.

Second; a user's expenditures may not accurately reflect his/her own consumption. In Svalna, the GHG emissions are always allocated to the person who pays, although someone else may be consuming the goods or service (consider, e.g., parents that buy clothes for their children, or a user who uses her private account to pay for a business trip and is later reimbursed). Svalna has tried to solve this by offering the possibility to disregard purchases that are not consumed by the user, or that shall be allocated elsewhere (e.g., to an employer). Further, families typically exhibit a variety of financial solutions. One family member may pay for heating, while another family member may buy all the food. Svalna handles this by automatically splitting the GHG emissions from the household's electricity and heating bill on all members of the household, and by allowing users to split accounts and specific costs. Since users are naturally more interested in (rightly) allocating emissions to others, but less interested in fully accounting for their own emissions when someone else pays the bill, these features could underestimate users' GHG emissions. Svalna is currently investigating the opportunity to handle this issue by allowing users to create "household groups" in which users living together could allocate GHG emissions between each other and also to household members who are not using Svalna (such as children).

Using financial transaction data paired with GHG intensities from EE-MRIO models thus seems to be a promising path that may provide a foundation for consumption-based GHG estimates that could be used by different actors. The current development suggests that several banks in the Nordic and European countries may soon begin to provide their customers with simplified carbon footprint estimates and if the actors about to enter this market choose to develop separate schemes, it may lead to uncertainty regarding which estimates to trust. There is hence a need for a transparent standardized system, which EE-MRIO models could provide given their robustness and potentials for improvement. The solution developed by Svalna for Sweden could be expanded to other European countries.

6. Conclusions

The current shift in policy debate, which no longer considers technological development and unilateral agreements sufficient to tackle climate change, opens up for other avenues to engage and involve citizen consumers in the transition to a more sustainable society. Seen in this context, carbon calculators may play a role in encouraging people to learn more and take active measures to change their behavior.

This paper describes how financial transaction data may be paired with EE-MRIO models to provide a foundation for rough but reliable estimates of users' carbon footprints. The idea of using transaction data to estimate GHG emissions is now being developed by several businesses, which suggests that the public at large may soon be able to see their carbon footprints on different digital platforms. This development may merit renewed interest in establishing a transparent standard regarding how personal carbon footprints should be calculated. Svalna's approach has several merits as it makes measurements relatively straightforward, relies on existing and transparent systems that are already used for official reporting to the UNFCCC, and that are also likely to be improved over time. It remains to be seen if, how and under which circumstances providing people with information on their carbon footprint has the potential to directly or indirectly affect the societal transformation towards reduced GHG emissions.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: David Andersson is the founder and owner of Svalna Inc.

CRediT authorship contribution statement

David Andersson: Conceptualization, Writing - original draft, Writing - review & editing, Resources.

Acknowledgements

I would like to thank Maria Nordborg, Ross Linscott and Mikael Klintman for offering helpful comments on earlier versions of this manuscript. Any remaining errors or inaccuracies must remain the fault of the author alone. I also wish to thank colleagues at Gothenburg University, Environmental Psychology Unit, and former colleagues at Chalmers University of Technology, Physical Resource Theory, for sharing thoughts and ideas from their respective fields. This research is part of the programme Mistra Sustainable Consumption, funded by Mistra — The Swedish Foundation for Strategic Environmental Research (Grant number 2016/3).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jclepro.2020.120396.

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