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Living within a One Planet reality: the contribution of personal Footprint calculators

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Abstract

During the last 50 years, humanity's Ecological Footprint has increased by nearly 190% indicating a growing unbalance in the human-environment relationship, coupled with major environmental and social changes. Our ability to live within the planet's biological limits requires not only a major re-think in how we produce and distribute 'things', but also a shift in consumption activities. Footprint calculators can provide a framing that communicates the extent to which an individual's daily activities are compatible with our One Planet context. This paper presents the findings from the first international study to assess the value of personal Footprint calculators in guiding individuals towards sustainable consumption choices. It focuses specifically on Global Footprint Network's personal Footprint calculator, and aims to understand the profile of calculator users and assess the contribution of calculators to increasing individual awareness and encouraging sustainable choices. Our survey of 4245 respondents show that 75% of users resided in 10 countries, 54% were aged 18–34 years and had largely used the calculator within an educational context (62%). The calculator was considered a valuable tool for knowledge generation by 91% of users, and 78% found it useful to motivate action. However, only 23% indicated the calculator provided them with the necessary information to make actual changes to their life and reduce their personal Footprint. The paper discusses how and why this personal Footprint calculator has been effective in enhancing individuals' understanding of the environmental impact of their actions, framing the scale of the problem and empowering users to understand the impacts of different lifestyle choices. Those individual-level and system-level changes needed to generate global sustainability outcomes are also discussed. Similar to other calculators, a gap is also identified in terms of this calculator facilitating individuals to convert new knowledge into action.

1. Introduction

Creating sustainable societies and socio-economic systems depends on our capacity to understand and manage human-environment interactions (WCED 1987, Costanza *et al* 2014, Sterner *et al* 2019). During the last decade, an increasing number of studies have highlighted the role humans have played, and continue to play, in altering the biophysical dynamics of the planet, and the need for unsustainable economic and social trends to be inverted (e.g. Moore *et al* 2012, Barnosky *et al* 2016, Davis *et al* 2016, Bjørn *et al* 2018, Steffen *et al* 2018).

Although we live in a One Planet reality (Ward and Dubos 1972), humans currently demand the equivalent of 1.7 planets worth of resources and ecological services (WWF *et al* 2018)—with major imbalances across countries (Galli *et al* 2014, Lin *et al* 2018)—resulting in a noticeable decline in the world's biodiversity (Butchart *et al* 2010, Tittensor *et al* 2014, Diaz *et al* 2019) and threatening the well-being of future generations (O'Neill *et al* 2018) and the planet's stability (Steffen *et al* 2015a).

Informed by such studies, work of international bodies (e.g. IPCC 2014, SCBD 2014, Diaz *et al* 2019), and coupled with pressure from global public movements, policy makers are becoming increasingly aware of the need to revise policy choices and investment decisions, and promote policies to stimulate long-term changes in beliefs, social norms and human behaviours (Kinzig *et al* 2013). As demonstrated by the Paris Agreement (UNFCCC 2016), the ongoing UN debate on a Global Pact for the Environment[6], and citizen movements (e.g. Fridays for Future, Extinction Rebellion), momentum is rapidly developing and should now be leveraged to trigger socio-economic and cultural changes towards sustainable development.

Decisions are made every day by policy makers, businesses and citizens that have significant effects on the future sustainability of humanity (DeFries *et al* 2004). All stakeholders are essential and their actions complement each other, however, as the issues of sustainability governance and related decision-making processes are investigated by many (e.g. Dietz *et al* 2003, Magalhães *et al* 2016, Galli *et al* 2018, Brown *et al* 2019, Sterner *et al* 2019), discussing the role of global policy processes is beyond the scope of this paper, instead it focuses on the 'other side of the coin': the role of individuals.

Sustainable production ensures products are produced efficiently while protecting public health and the environment, but it may be insufficient to reduce the overall impact of a growing human population on the biosphere, sustainable production thus needs to be coupled with measures and approaches that address consumption (Jackson 2005) and increased knowledge of the effectiveness of consumers' options and lifestyle choices (e.g. Wynes and Nicholas 2017 and Moran *et al* 2018). Affluence, human behaviour and personal daily choices, among other things, determine individuals' consumption of resources (Myers and Kent 2003, Weinzettel *et al* 2013, Collins *et al* 2018), and affect the ability of our planet to support ever increasing demands. Global public movements (e.g. 'Fridays for Future') can trigger actions by policy makers, which in turn act as feedback loops on human-environment relationships (Hagedorn *et al* 2019). As such, progressive awareness through learning-by-doing activities, life-long education and knowledge of the implications of consumption choices are prerequisites for supporting shifts towards sustainable behaviour and practices (Blumstein and Saylan 2007).

In this context, interactive tools such as online calculators and simulators (e.g. West *et al* 2015, Buhl *et al* 2017, Collins *et al* 2018, Mulrow *et al* 2019), the gamification of sustainability (e.g. Morford *et al* 2014, Negruşa *et al* 2015, Nordby *et al* 2016, Oppong-Tawiah *et al* 2018, AlSkaif *et al* 2018, Gatti *et al* 2019), and participatory citizen science approaches (e.g. Kythreotis *et al* 2019) have become increasingly popular for measuring and communicating the environmental impacts of individual resource use and can contribute to delivering on global goals (e.g. Paris Agreement, 2030 Agenda for Sustainable Development).

This paper aims to understand the profile of calculator users and assess their contribution in increasing individual awareness, encouraging sustainable choices, and building One-Planet-consistent identities (i.e. sustainability seen as necessary, not noble). A number of Footprint calculators have been developed in the last decade, many of which are available online (see for example WWF Footprint calculator, Henkel Footprint calculator, CarbonFootprint calculator and EPA Victoria's Australian Greenhouse Calculator); however, they vary in terms of their scope, methodology, assumptions, and definition of 'Footprint' (see Collins and Flynn 2015, Collins *et al* 2018).

This paper specifically focuses on Global Footprint Network's (GFN) personal Footprint calculator[7]—a freely available online calculator—and aims to answer the following research questions:

1. Who has used the personal Footprint calculator, how often, and what are their reasons for using it?
2. How valuable is the calculator perceived by its users?
3. What were users' Footprint results? How do they compare with the global average and humanity's Earth Overshoot Day?
4. Which personal Footprint results are considered most valuable?
5. To what extent has the personal Footprint calculator motivated users to make changes, and in which consumption areas?

2. Measuring and communicating human pressure on the planet: an overview of the Ecological Footprint

Introduced in the early 1990's by Mathis Wackernagel and William Rees (Rees 1992 1996, Wackernagel *et al* 1999), Ecological Footprint Accounting (EFA) has been gaining popularity ever since (Collins and Flynn 2015, Galli 2015), due to its apparent ease of use (Giampietro and Saltelli 2014, Galli *et al* 2016), communication

[6] See https://unenvironment.org/events/conference/towards-global-pact-environment for further details.

[7] Global Footprint Network is an international NGO working to change how the world manages its natural resources and responds to climate change through Ecological Footprint accounting and awareness-raising activities. The calculator is available at: http://footprintcalculator.org/.

simplicity (Wiedmann and Barrett 2010), and its capacity to serve as a proxy measure for quantitatively assessing human-environment relationships. Composed of two metrics—Ecological Footprint and biocapacity—EFA tracks human demand for, and nature's supply of, key resource provisioning and regulating ecosystem services (Mancini *et al* 2018). This offers a biophysical approach capable of quantifying the demand humans place on the planet's ecosystems—the Ecological Footprint—and benchmarking it against the actual ecosystems' capacity to support such demand —the biocapacity (Borucke *et al* 2013, Galli *et al* 2014, Lin *et al* 2018, Wackernagel *et al* 2019).

EFA provides Ecological Footprint and biocapacity results in global hectares (gha), a globally comparable measure of world-average productivity (Borucke *et al* 2013). These results inform individuals about how much bioproductive land-equivalents they demand based on their daily activities (Galli 2015). The resources and ecosystem services tracked by the Ecological Footprint and the six land types that provide them are: cropland for providing plant-based food and fibre products; grazing and cropland for animal products and livestock feed; fishing grounds (marine and inland) for seafood products; forests for timber, other forest products, and to sequester waste (CO_2, primarily from fossil fuel burning); and built-up land for shelter and other urban infrastructure (Borucke *et al* 2013, Mancini *et al* 2018).

The availability of biocapacity is calculated as the sum of the biocapacity supplied by each land type, that is the rate of resource provisioning and regulating ecosystem services (i.e. effluent waste disposal) that can be sustained by that land type under current technology and management schemes (Monfreda *et al* 2004, Borucke *et al* 2013).

The Ecological Footprint and biocapacity offer a biophysical lens to understand and manage our planet's resources—which ultimately contribute to humanity's success and well-being (Mancini *et al* 2018)—without dictating 'how societies should develop' (Steffen *et al* 2015b). Nonetheless, the Ecological Footprint has not been exempt from criticism and its methodology and policy usefulness have been deeply scrutinized by the scientific community (e.g. Costanza 2000, Kitzes *et al* 2009, Giampietro and Saltelli 2014, Goldfinger *et al* 2014, Lin *et al* 2015, Galli *et al* 2016). While skepticism exists on its policy usefulness (e.g. Fiala 2008, Van den Bergh and Grazi (2013)), a general agreement seems to prevail about its communication value (e.g. Wiedmann and Barrett 2010, Collins and Flynn 2015, Fernández *et al* 2016).

3. Understanding individual Footprint calculators: a brief overview

3.1. Review of previous calculator-related studies

Footprint calculators can play an important role in increasing individual awareness of the environmental impacts associated with consumption choices. To date, the majority of published articles on calculators have focused specifically on online carbon calculators (e.g. Padgett *et al* 2008, Birnik 2013), with relatively less attention given to personal Ecological Footprint (EF) calculators.

Previous studies have sought to compare and contrast Ecological Footprint calculators. Franz and Papyrakis (2011) analysed six online calculators and identified several positive features such as (1) comprehensive and location-specific questions; (2) information alongside questions explaining why certain options were 'greener' (i.e. directing individuals to improved choice making); and (3) enabling users to purchase carbon-offsetting credits. However, several calculators did not provide detailed information on the methodology behind individual's Footprint results, nor did they provide 'truly' best sustainable options to fully mitigate an individual's environmental impact. Their analysis also found that when the most environmentally friendly responses for calculator questions were selected, an individual's Ecological Footprint still exceeded the planet's biocapacity, so possibly discouraging individuals from changing their consumption behaviour. Brook's study (2011) found that downbeat feedback in Ecological Footprint calculators negatively affected the behaviour of unconcerned individuals, although they still contributed to a marginal increase in pro-environmental behaviour by individuals already concerned about environmental issues.

More recently, Collins and Flynn (2015) compared four popular online individual Footprint calculators, and identified a number of similarities and differences. The calculators included in their analysis were brand-named by organisations (WWF UK, Best Foot Forward, Bioregional Group, and GFN), which Collins and Flynn (2015) argue can add credibility and confidence in the calculator results. All calculators included questions that related to five main consumption activities: food, waste, energy use at home, travel and goods/stuff. Similar to Franz and Papyrakis (2011), they found that several of the calculators did not provide methodological details, and when the most sustainable options were selected for each question, an individual's Footprint results (in all four calculators) still exceeded the available biocapacity.

All of the calculators reported individuals' Footprint results in terms of 'Number of Planets', and several reported detailed Ecological Footprint results by consumption activities. The comprehensiveness of the calculators was found to vary in terms of the number of questions and level of information required (i.e. predefined responses or actual quantities). However, when the Footprint results of each calculator were compared using the same lifestyle scenario, they found —similar to Franz and Papyrakis (2011)—no evidence to suggest there was a link between a calculator's comprehensiveness and difference in its results.

While Ecological Footprint calculators have the potential to be powerful communication tools, incentivize change, and aggregate the environmental impacts of resource consumption into a single measure (i.e. global hectare), Franz and Papyrakis (2011) argue their current design may be preventing them from being an effective tool for translating environmental concern into public action. To achieve this, they highlight that calculators need to (1) incorporate a detailed description of the methodology used to calculate results, (2) illustrate the links between individual choices and the aggregated environmental impact, (3) clearly frame the scale of the problem, and (4) provide options that demonstrate how to prevent ecological deficits.

This study differs from previous analysis of Ecological Footprint calculators in several ways. First, it provides an in-depth insight into international users experience and perceptions of a popular personal Footprint calculator. Second, it examines how and why this calculator has been effective in enhancing individuals' understanding of the environmental impact of their actions. Finally, it seeks to identify the extent to which this calculator is able to facilitate individuals to convert new knowledge into action.

3.2. Global Footprint Network's personal Footprint calculator

GFN's personal Footprint calculator was initially developed in 2007 to highlight resource consumption at the individual level and close the 'gap' between nationally focused work (i.e. the *National Footprint and Biocapacity Accounts*) and awareness-building communication campaigns. In 2017, it was redesigned to enhance the user interface, improve the user experience and update the underlying data; this calculator is now mobile-friendly, accessible across a range of devices, and available in several languages (e.g. Chinese, English, French, German, Hindi, Italian and Spanish).

The data underlying the personal Footprint calculator is from the *National Footprint and Biocapacity Accounts*, which use up to 15 000 data points per country-year (Lin *et al* 2018). However, the personal Footprint calculator diverges from traditional NFA assessment as it asks the user a series of lifestyle questions (ranging from 17 basic questions to 29 detailed questions) about food, housing, energy, mobility, goods and services, and uses scale responses[8] (e.g. 'Never' through to 'Very Often') rather than specific data points (see figure 1 for example questions) to derive individual results. The inclusion of questions with scaled responses may not be as precise as inputting specific data; however, it can make calculators more accessible to users with different abilities and levels of understanding (Gottlieb *et al* 2012). In addition, some of the calculator questions provide information on the impact of different responses and how impact could be reduced.

The calculator provides four results: Personal Overshoot Day (POD)[9], number of Planet Earths, Ecological Footprint (by consumption category and land type), and CO_2 emissions per year (see figure 1). It also allows users to explore solutions to reduce their Footprint in five key areas affecting short- and long-term resource demand (City, Energy, Food, Population and Planet).

4. Methodology: assessing user experience and perceptions of the personal Footprint calculator

This study used an electronic survey to obtain information from individual users on their experience and perceptions of GFN's personal Footprint calculator and its results. This was preferred to off-line alternatives (e.g. paper or telephone survey) due to its cost advantage (economic and environmental), faster data handling and possibility of reaching international users.

The survey was designed using Qualtrics™ (www.qualitrics.com), an online survey tool frequently used to design and conduct market research and evaluations. Qualtrics™ was selected over other tools as it enabled us to incorporate a variety of question types as well as skip and branching logic. This was necessary to capture an in-depth and robust understanding of users experience and perceptions of the calculator and their personal Footprint results. The survey contained questions dealing with user profile (gender, age, country of residence, occupation), reasons for using the calculator, experience and perceptions of the calculator, personal Footprint results and their motivational effect, and suggestions on how the calculator could be improved (see table A1).

Prior to conducting the survey, it was piloted amongst a small number of academics and Footprint practitioners to gain feedback on its length, clarity and order of questions, and the suitability of response categories. The final survey—which took approximately 20 min to complete—was distributed electronically to 192 300 registered users of GFN's personal Footprint calculator. Users were contacted by email in August 2018 with details on who was conducting the study, its purpose, and a direct link to the online survey. This was followed up with two reminders over a three-week period in an attempt to increase the response rate, and reduce the possibility of non-response bias (Schuldt and Totten 1994). Although users of this calculator

[8] Scale responses are used by the calculator to increase or decrease the amount that an individual's Ecological Footprint is distributed into the different Footprint components relative to the world-average.

[9] Personal Overshoot Day (POD) indicates the date in the year when humanity would have exhausted the planet's annual ecological budget if everyone on the planet lived like the person taking the calculator.

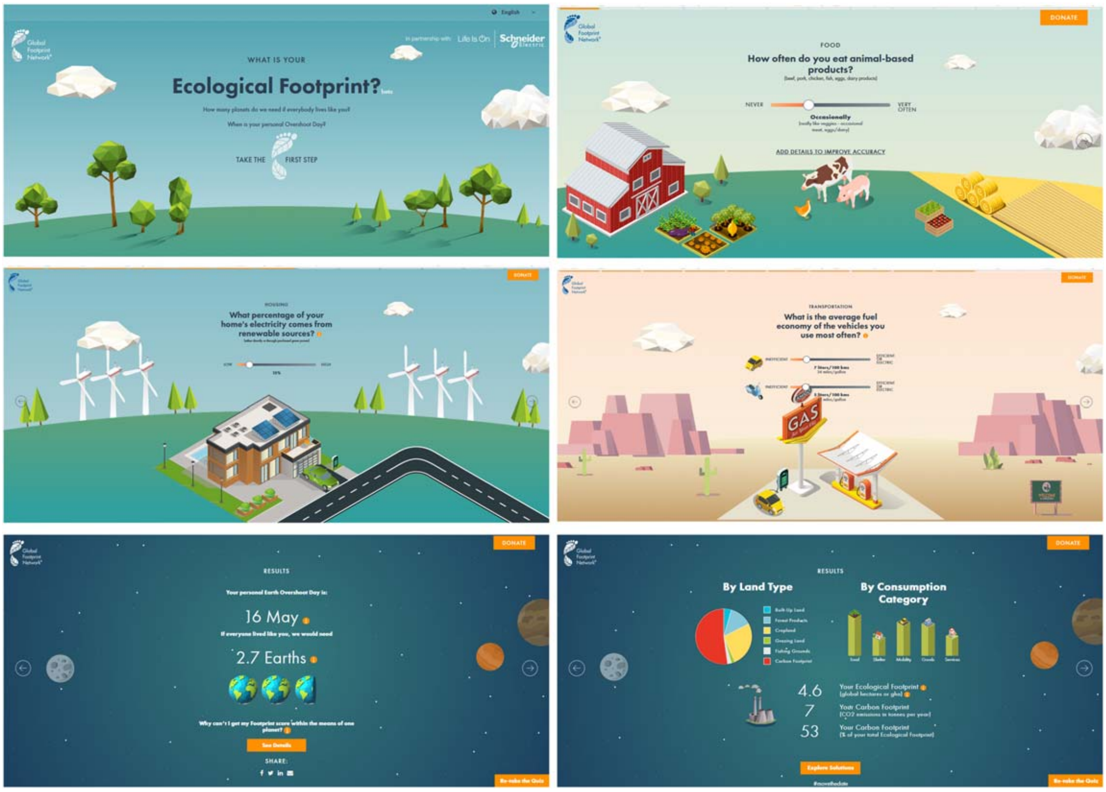

Figure 1. Selected screenshots of GFN's personal Footprint calculator (Global Footprint Network 2019). Details on the data and calculation mechanism that underpin GFN's personal Footprint calculator are provided in Collins *et al* (2018).

were located across the world, the survey was only provided in English. Overall, 4245 users fully completed the survey. Responses were downloaded from the survey software and collated without identifiers/email addresses before the analysis.

5. Results and discussion

5.1. User profiles

Overall, 4245 individuals (2.2% of the 192 300 registered users) fully completed the survey. Table 1 shows respondents by world region and country, and provides information on each country's corresponding Ecological Footprint value (per capita) and world ranking (in 2014).

The largest percentage of survey respondents resided in North America (45.1%), followed by Europe (26.9%) and Asia-Pacific (13.9%). World regions with the smallest percentage of respondents were Africa and Middle East/Central Asia (both at 2.2%). It is not surprising that the second largest proportion of respondents resided in Europe, as this region has historically shown the greatest interest in the Ecological Footprint and its message (Collins and Flynn 2015). However, it was somewhat unexpected that the largest percentage of respondents resided in North America: engagement with the Ecological Footprint in this region has been historically low, although a recently published report which assesses natural resource supply and use in all 50 states of the USA (GFN and Earth Economics 2015), and York University in Canada is in the process of becoming the global datacenter for National Footprint Accounts production[10].

Country-wise, the largest percentage of respondents lived in the United States (35.8%), followed by Canada (9.3%) and Australia (8.6%) (see table 1). Interestingly, these three countries were also among the top 11 countries with the largest national per capita Ecological Footprint in 2014 (see Lin *et al* 2018, WWF 2018). Among the 10 countries with the most respondents, only Mexico had a per capita Ecological Footprint (2.55 gha) lower than the world average (2.83 gha); all countries had an Ecological Footprint higher than the globally available biocapacity per person (1.68 gha).

5.1.1. Gender, age and occupation

The largest percentage of respondents were female (60%), although differences exist among world regions. In North America, Asia-Pacific, Europe and Africa the largest percentage of respondents were female, while in Central America/Caribbean, Middle East/Central Asia and South America the largest percentage of respondents were male (figure 2(a)).

In terms of age-profile, most respondents were aged 18–24 (35%) and 25–34 (20%) years, although regional differences were observed (figure 2(b)). The percentage split between these two age groups varied across world regions, with the 18–24 year group

[10] See more details et: https://footprint.info.yorku.ca/.

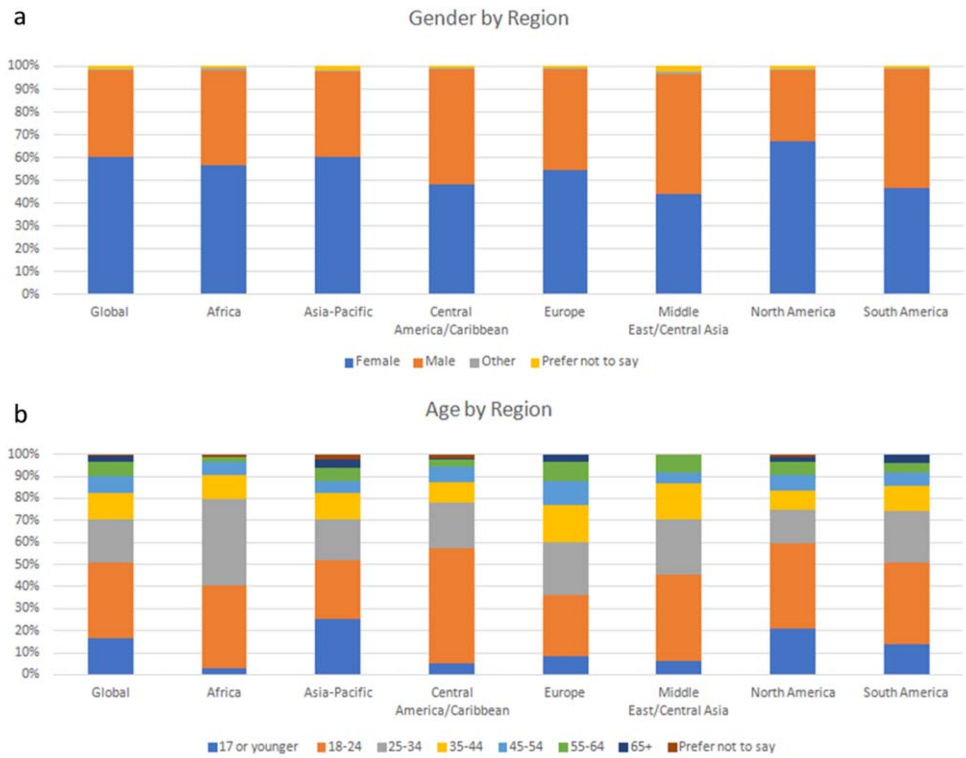

Figure 2. Respondent by gender (a) and age (b) by world regions.

Table 1. Respondents by world region, country, national Ecological Footprint (per capita) and world ranking.

Country	Number of respondents (#)	Percentage of respondents (%)	2014 Ecological Footprint (gha capita^{-1})[a]	2014 Ecological Footprint world ranking
		World region		
North America	1914	45.1	—	—
Europe	1132	26.9	—	—
Asia-Pacific	589	13.9	—	—
South America	213	5.0	—	—
Central America/ Caribbean	211	5.0	—	—
Africa	94	2.2	—	—
Middle East/ Central Asia	92	2.2	—	—
		Country		
United States	1520	35.8	8.37	6
Canada	395	9.3	8.05	7
Australia	365	8.6	6.89	11
United Kingdom	233	5.5	4.80	39
Mexico	140	3.3	2.55	92
Italy	136	3.2	4.29	52
France	123	2.9	4.70	42
Germany	102	2.4	5.05	35
Brazil	76	1.8	3.08	80
Netherlands	68	1.6	5.92	20

prevailing in the Americas. In Asia-Pacific and North America, the second largest share of respondents was 17 years and younger (25% and 21%, respectively). Europe and the Middle East/Central Asia, conversely, had the largest percentage of respondents aged 35–44 years (16% and 17%, respectively).

In terms of occupation, almost 62% of users described themselves as being/working in 'Education', which included teachers/university professors and students. The second and third largest categories were business (6.4%) and service sector (4.9%). It is not surprising that the largest percentage of respondents came from the

Table 2. How respondents became aware of the calculator and who they recommended it to.

Heard from…	Percentage of respondents (%)	Recommended to…	Percentage of respondents (%)
Teacher/professor	46.2	Friend	41.9
Web search	17.0	None	32.5
Social media	16.0	Family member	29.2
Global Footprint network	13.8	Colleague	12.9
Friend or family member	7.4	Students/Classmates	4.9
Work colleague	6.5	Other	1.8
Media	5.9	Social media	0.8
Other	4.3	Teacher/professor	0.1

'Education' sector, as the use of the Ecological Footprint in educational establishments has received increasing attention since 2001 (see Collins *et al* 2018), including training of elementary school teachers and other educators in Spain (Fernández *et al* 2016), United States[11] and Italy[12].

5.1.2. Calculator awareness and access

The largest percentage of respondents (46%) had heard about the calculator through their teacher/professor, followed by web searches (17%), social media (16%), and directly from GFN (14%). A further 13.9% heard about the calculator through friends, family members or work colleagues, and 5.9% from the general media (see table 2). Results confirm that the education sector has been a key avenue through which users have accessed the calculator and, more generally, Ecological Footprint data and information.

The largest proportion of respondents (84%) had used the calculator in the most recent year, with 40% using it during the 3 months prior to the survey. The calculator was used for more than a year by 16% of respondents, with about 5% of users indicating a prolonged use over time (more than 4 years). Almost three quarters of respondents had used it 1–2 times, with a similar frequency of use by gender (figure 3(a)) and age group (figure 3(b)). A marginally larger proportion of respondents aged 17 years or younger and 45–54 years had used the calculator more than 3 times, and those aged 55–64 and 65+ years had used the calculator 6 times or more.

Figure 4 shows the main reasons for using the personal Footprint calculator, which can be grouped into three broad categories: the first reason relates to *calculating their Ecological Footprint*, the second to enhancing users' *knowledge and understanding* of what a Footprint is and how to reduce it, while the third category relates to the calculators' *functional purpose*, which included comparing the calculator with others, for teaching/education purposes and being asked by their employer.

[11] See the guide by Vanderbilt University at https://cft.vanderbilt.edu/guides-sub-pages/teaching-sustainability/#foot.

[12] See https://fondazionemps.it/al-via-scool-food-per-educare-i-giovani-ad-un-consumo-consapevole/ and www.ecodynamics.unisi.it/?p=1686 [both in Italian].

5.2. Value of the personal Footprint calculator and its results

5.2.1. User experience of the calculator

Reflecting on their experience in using the personal Footprint calculator, the most commonly used words by respondents ranged from, *interesting* and *informative* through to *easy* and *fun*, and *shocking* and *surprising*. To obtain a detailed understanding of respondents' perceptions about the calculator, they were asked to indicate the extent to which they agreed or disagreed with a number of statements about specific features of the calculator (see table 3).

The overwhelming majority of respondents strongly agreed/agreed that the calculator was *easy to use* (93%), and helped them *understand what an Ecological Footprint is* (91%). A significant proportion of respondents also strongly agreed/agreed that it had helped them *understand what their Personal Overshoot Day is* (82%), the *impact of their actions* on the planet (93%) and which *aspects of their life had the greatest impact* (87%). For 86% of respondents, using the calculator also led them to think about *how to reduce their impact* on the Earth, and 78% of respondents were *inspired/motivated […] to take action* to reduce their personal Ecological Footprint on the planet. Moreover, 74% of respondents strongly agreed/agreed that the personal Footprint calculator is *more informative than other footprint calculators*. More than two-thirds of respondents recommended the calculator to others, in particular friends (41.9%), family (29.2%), and work colleagues (12.9%) (table 2).

However, 67% of respondents strongly agreed/agreed that the calculator had left them confused because of the four different results generated by the calculator (i.e. Personal Overshoot Day, Ecological Footprint, Number of Planet Earths and CO_2 emissions) (table 3). Also, only 23% of respondents strongly agreed/agreed that the calculator had provided them with the *necessary information* to make changes to their life and reduce their personal Footprint (28%). These results suggest that while the calculator can be an effective tool for enhancing individuals' understanding of the environmental impact of their lifestyles, and inspire them about making changes to reduce their personal Footprint, a gap still exists in converting acquired knowledge into actual life changes.

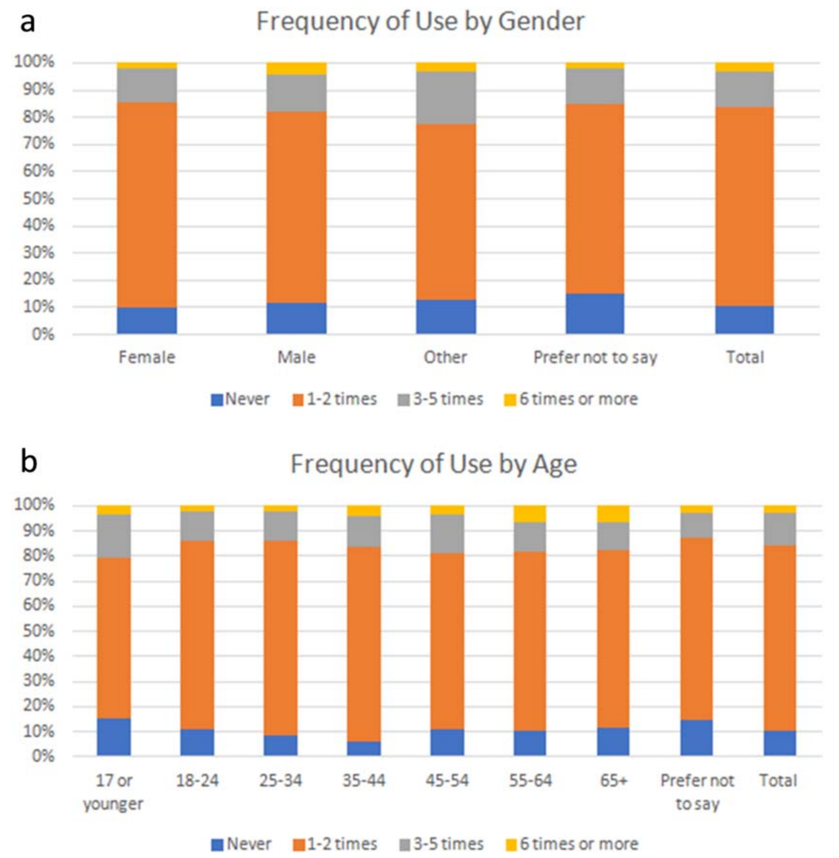

Figure 3. Respondent frequency of use by (a) gender and (b) age group.

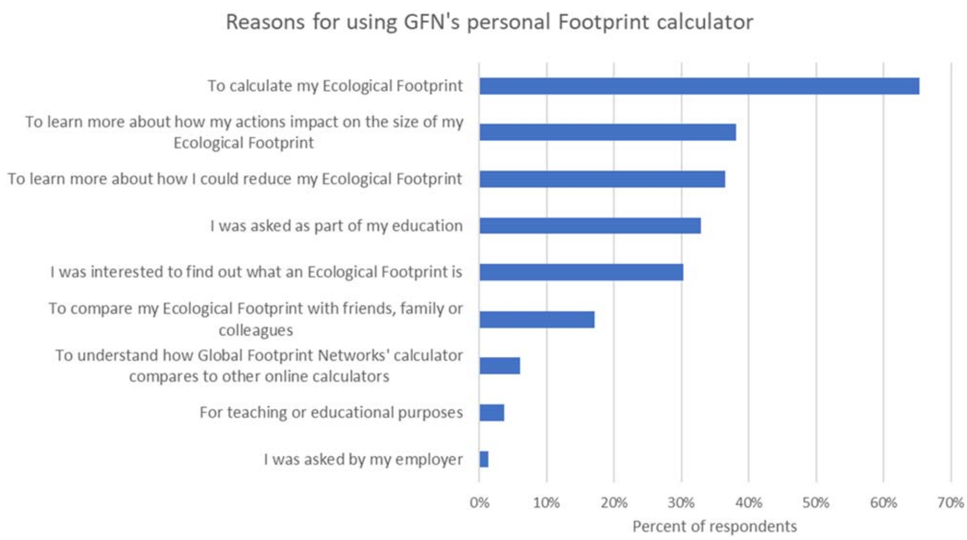

Figure 4. Respondents' reasons for using GFN's personal Footprint calculator.

5.2.2. User Footprint results

Most respondents were able to recall their result for Number of Planets (59%), and Personal Overshoot Day (31%), while significantly fewer respondents were able to recall their personal Ecological Footprint (14%) or CO_2 emissions (12%) (table 4). Nonetheless, respondents indicated *Number of Planets* (65%) followed by *Ecological Footprint* (31%) as the most useful results in helping them understand the impact of their actions on the planet, while *Personal Overshoot Day* and *CO_2 emissions* were considered the least useful result in informing users about their personal environmental impact (27% and 21% respectively). Only 4% of respondents found none of the results useful.

Our study highlights that users' current mean level of resource use (4.6 gha per capita) exceeds the Earth's

Table 3. User perceptions of the personal Footprint calculator.

Statement	Strongly Agree/ Agree (%)	Unsure/ Undecided (%)	Strongly disagree/ disagree (%)
Is easy to use	93	6	1
Is important for understanding what impact my actions have on the planet	93	6	1
Has helped me understand what an Ecological Footprint is	91	7	2
Has helped me understand what aspects of my life have the largest impacts on the planet	87	10	3
Has led me to think more about how I can reduce my impact on the Earth	86	11	3
Has helped me understand what my Personal Overshoot Day is	82	15	3
Has inspired and motivated me to take action to reduce my personal Ecological Footprint	78	17	5
Clearly explains key terms and phrases	76	20	4
Is more informative than other Footprint calculators	74	24	2
Has made me feel uncertain about what difference one person can have by making changes in their life	69	22	9
Has left me feeling confused because of the different results (Personal Overshoot Day/Number of Earths/Ecological Footprint)	67	24	9
Provides valuable advice on the changes I can make to reduce my personal Footprint	28	22	50
Provides me with the necessary information so that I can make changes to my life	23	24	53

Table 4. Number of users who recalled their result for each indicator, average results, and usefulness of indicators.

Indicator	Total responses	Average response	Most useful
Personal overshoot day	1321	June (median)	27%
Number of planets	2517	4.6 (mean)	65%
Ecological Footprint (gha year^{-1})	586	4.7 (mean)	31%
CO_2 emissions (tonnes year^{-1})	515	14.3 (mean)	21%

capacity to meet that demand as indicated by the world average biocapacity of 1.68 gha per person (Lin *et al* 2018, WWF 2018). This may be due to a large proportion of survey respondents residing in North America and Europe, with a larger average Ecological Footprint per capita (table 1). This also suggests that users of the calculator may have anticipated having a large personal 'Footprint' and were intrigued to use it to measure the actual scale of their impact on the planet. Furthermore, regions such as North America and Europe are also those in which conversations on climate change and sustainability are high on the media agenda, another factor that may have triggered users' interest in finding out more about these topics and their personal contribution to them.

Despite only 14% of respondents recalled their personal Ecological Footprint result, 31% of respondents stated they considered it to be the most useful result. While the *Number of Planets* result provides users with an overall understanding of the degree to which their lifestyle is (in)compatible with the One Planet context (most likely moving their emotions), detailed Ecological Footprint results by land types and consumption activities (see figure 5), inform users about the drivers of their demands, thus triggering initial reflections on the type of changes they are willing/unwilling to consider.

Our results show that the category with the highest level of resource consumption was 'Mobility' (48.5%), followed by 'Food' (28.3%) and 'Shelter' (10.5%). Some variation was found across different genders, age groups, and regions. Across genders, the contribution of each consumption category to Footprints was fairly similar, although the 'Goods' category was marginally larger for female respondents and 'Mobility' was marginally larger for males (figure 5(a)). Across age categories (figure 5(b)), respondents aged 65+ years had the highest 'Mobility' Footprint and the smallest 'Goods' Footprint. This may be due to having more time and resources to travel during retirement, and purchasing fewer goods (i.e. new clothing, furniture or electrical equipment). 'Shelter' had the highest value for respondents aged 18–24 and 45–54 years, while 'Goods' had the highest value for people 55–64 years old. Finally, the contribution of each consumption category also varied by region (figure 5(c)). A noticeably higher 'Food' share of the overall Footprint was observed in Africa (39% of the total regional Footprint), while 'Mobility' contributed to a particularly larger share of the regional Footprint value in the Middle East (55% of the total regional Footprint) and South America (52%). The share due to 'Shelter' was

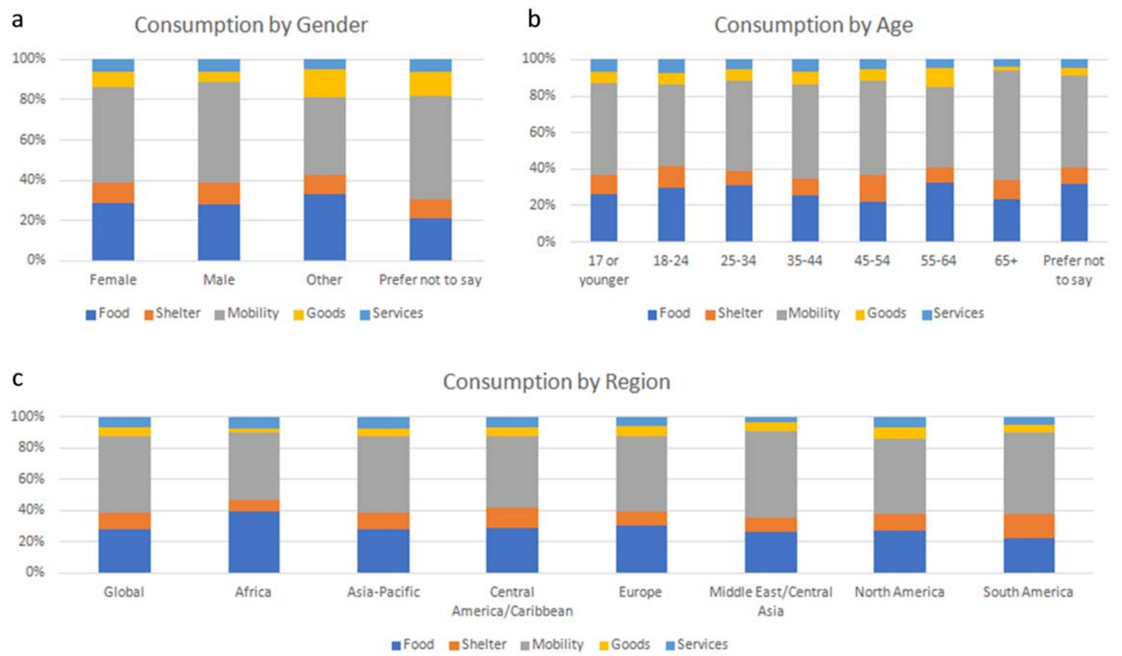

Figure 5. Ecological Footprint results by consumption category across (a) gender, (b) age, and (c) region.

higher in South America (15%) and Central America/Caribbean (13%) than the global average (10%), while the 'Goods' category was particularly low for respondents living in Africa (3%), and the 'Services' category was low for respondents living in the Middle East (3%). These results can be explained by the difference in income level and affluence of people across world regions. For example, food constitutes a basic need and is the biggest part of the resource requirements for households in low-income countries while expenses on services, transport and housing are higher in wealthier households and tend to increase with increasing income levels (see also Duro and Teixidó-Figueras 2013, Weinzettel *et al* 2013, Baabou *et al* 2017).

5.2.3. Inspired to make changes

Most respondents (78%) stated they were inspired to make changes in one or more of the five consumption categories (table 3), with 'Food' (56%) and 'Waste and Recycling' (56%) being the two areas of consumption in which respondents were most inspired to make changes, followed by 'Travel' (47%), 'Energy' (38%) and 'Housing' (27%) (figure 6(a)). 22% percent of respondents stated they were undecided or not inspired to make changes in their lives (table 3). When specifically asked about the changes they were not prepared to make, the largest proportion of respondents (61%) mentioned travel-related changes (figure 6(b)), despite the calculator results showing users that 'Travel' contributes significantly to their personal Footprints.

A possible reason for users having a greater willingness to take actions related to 'Food' and 'Waste and Recycling', may be due to the perception that these areas would not require significant investments or changes in their day-to-day lives. Conversely, changes related to energy use and housing may require significant investments. In the case of young users, they have less control over their housing situation and may have a limited perception of responsibility if they live with their family (Collins *et al* 2018). Similarly, changes to 'Mobility' may involve difficult lifestyle choices (e.g. commuting to work by bike versus personal car) and time investments.

It should however be noted that these results only relate to respondents' self-reported willingness to change rather than actual behaviour changes. A higher degree of user engagement would be needed to fully understand the impact of life-long sustainability education in triggering enduring life changes.

6. Conclusions

Sustainability is a cross cutting issue and requires all actors in society, from policy makers to single individuals, to be involved in the co-creation of sustainable socio-economic alternatives. Scientists around the world are increasingly claiming that a systemic approach should be used by policy and decision makers to articulate a sustainable future for the human enterprise and ease long-term changes in beliefs, social norms and human behaviour (Barnosky *et al* 2012, Costanza *et al* 2014, Steffen *et al* 2015b, Broman *et al* 2017, Sterner *et al* 2019). Meanwhile, individuals are seeking to understand the nature and extent of the global environmental challenges society faces, and what they can do to contribute to a global solution.

Ecological Footprint calculators represent useful tools to guide users through the *knowledge-awareness-action* journey and are increasingly being assessed for

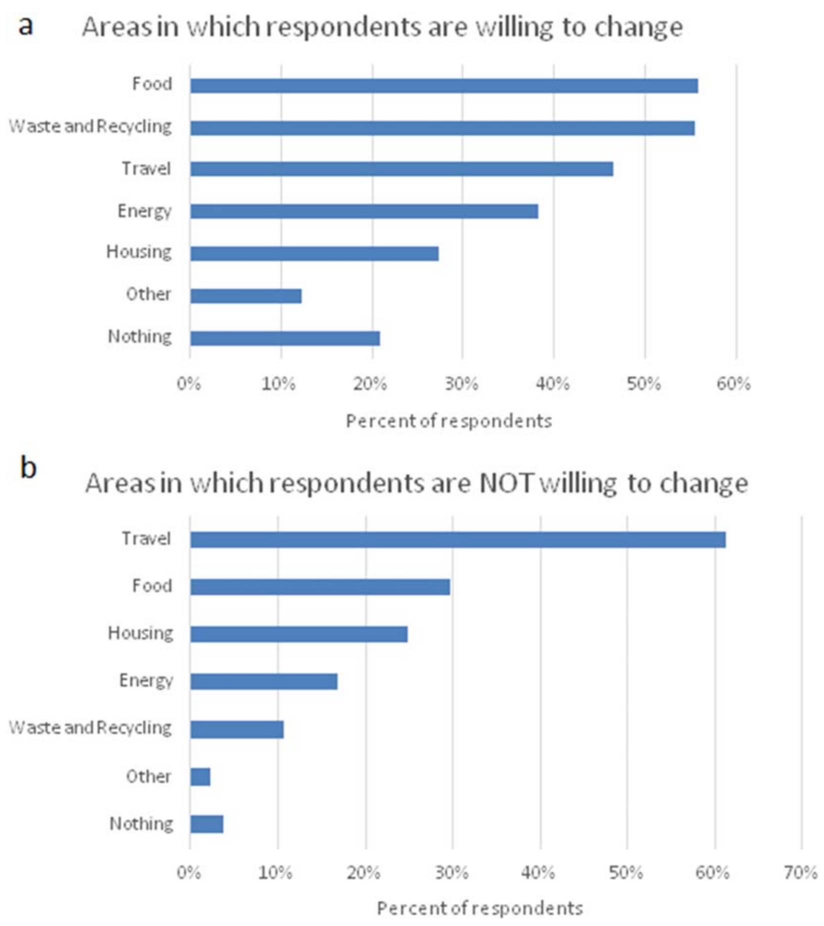

Figure 6. Areas in which respondents (a) are willing and (b) not willing to change.

their effectiveness in informing and educating individuals and triggering more sustainable lifestyle choices. This study provides strong evidence that GFN's personal Footprint calculator is an effective tool to help users embrace such a cross-cutting approach; it was considered helpful in knowledge generation and in motivating action by 91% and 78% of the respondents, respectively. The updated design and inclusion of specific features such as information on the impact of different consumption choices (e.g. cutting food waste, using cars versus walking, etc), and the presence of five solutions areas (City, Energy, Food, Population and Planet) were found to empower users and enhance their knowledge on the impact of different lifestyle choices, leading them to be inspired to take action to reduce their personal Footprint.

However, our study found that the majority of users were aged 18–34 years and predominantly from the educational sector (students or educators), suggesting that the calculator's current features, functionality and design might be attractive for this specific stakeholder group but fall short in providing policy and decision makers with the information needed to develop and implement alternatives. This suggests that the current policy contribution of calculators lies more immediately in their integration into education plans, for instance in primary, secondary and higher education curricula thus helping deliver on the UN Sustainable Development Goal 4, specifically target 4.7 (*By 2030 ensure all learners acquire knowledge and skills needed to promote sustainable development*).

Equipping schools and higher education institutions with powerful and captivating tools such as Footprint calculators could provide students with hands-on science-based knowledge, multidisciplinary skills and a much-needed transdisciplinary mindset; this would enable students to be better prepared for the future labour market while also contributing to the professional development of educators. Embedding Footprint calculators in curricula could also foster the development, testing and wider dissemination of a novel approach to sustainability teaching, to educate a future generation of sustainable citizens.

Nonetheless, our findings show that a gap still remains in enabling individuals to convert new knowledge into action: while 78% of respondents were inspired to make changes, about 50% of them didn't consider they had gained the necessary information on how to make changes, and 69% felt uncertain about the difference an individual can make. This highlights a second consideration from our study: although Footprint calculator results target individual users and trigger a bottom-up process to learn about sustainable lifestyle choices, the findings from this study should also be considered by decision and policy makers. These latter could gain insight on what is acceptable to people—also depending on the age, gender, occupation and geographical context—and thus contribute to the development of top-down policies and system-level changes that are necessary to generate lasting sustainability outcomes.

Finally, a few shortcomings in our research approach exist. The survey was only distributed in English, limiting participation in non-English speaking countries. Lower survey responses from those residing in regions other than North America and Europe may also be due to limited access to technology and the internet, and hints at the potential limited opportunities available for residents of these regions to receive life-long sustainability education through tools such as online Footprint calculators, simulators and games. This triggers a reflection on the generational and geographical gaps that exist in the capacity of users across the world to access sustainability related information, as well as the best tools and approaches to use in reaching out and engaging with less technologically-equipped stakeholder groups and populations.

Moreover, our survey did not obtain information on actual changes made by users as a result of using the calculator. Future research should focus on understanding which consumption areas users are or are not willing to make changes in, their reasons for focusing on specific areas, and barriers to adopting changes in other areas. This information could be used to develop individualised solutions, and assist in bridging the gap between being incentivized by the calculator and making actual change. We argue that providing users with additional data and examples of viable and functioning real-life alternatives could assist in bridging the gap between knowledge and action. Future research could thus embrace on-the-ground social science approaches such as surveys and in-person interviews to track this process of change.

Research in environmental psychology has shown that a direct, solutions-based approach is effective for users who have not previously engaged with many individual sustainable practices. However, users who already practice sustainable lifestyle choices benefit from activities that encourage self-determined motivation (Tagkaloglou and Kasser 2018). To account for differences in what motivates people to act, experiential activities or curricula allowing users to co-create their own solutions and scenarios could be developed; such a process could also contribute building sustainable identities (Crompton and Kasser 2010), which we deem essential for the systemic change needed to address the global environmental crisis.

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Data availability statement

Any data that support the findings of this study is included within the article. Beside such data, national Ecological Footprint results for all world countries can be freely accessed and downloaded at http://data.footprintnetwork.org/#/. Personal Footprint calculator can be accessed at: https://footprintcalculator.org/.

Appendix

Table A1. Main structure and topics of the survey.

Theme	Topic
Use profile	Gender
	Age
	Country of residence
	Occupation
User experience	Frequency (since re-launch in 2017)
	Duration
	Awareness of calculator
	Reason(s) for use
	Words or phrases to reflect overall user experience
	Statements about the calculator's design, value and how it compares with other calculators
	Recommendation to other users
Personal Footprint Results	Footprint results (Personal Overshoot Day, Number of Planets, Ecological Footprint and CO_2 emissions)
	Most and least useful calculator results
	Largest consumption category of the Personal Footprint
Motivation to make changes	Consumption categories in which users were prepared and not prepared to make changes
	Suggestions on how improve the calculator

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