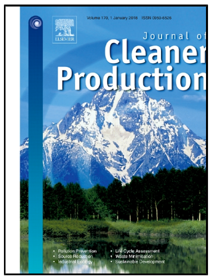

Learning and teaching sustainability: the contribution of Ecological Footprint calculators

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Highlights:

- Ecological Footprint (EF) has gained a prominent position in the sustainability debate since its introduction
- We used a personal Footprint calculator to teach environmental aspects of sustainability
- Students experienced at firsthand the multidimensional character of sustainability
- They gained insight on how daily activities affect the global sustainability discourse
- Our experiment is an effective way to initiate participative discussions on environmental sustainability

Learning and teaching sustainability: the contribution of Ecological Footprint calculators

by *Andrea Collins, Alessandro Galli, Nicoletta Patrizi* and *Federico Maria Pulselli*

Wordcount: 7,826 words

Abstract

Consumption habits imply responsibility. Progressive awareness of the scale of materials, energy, goods and services consumed on a daily basis and knowledge of the implications of consumption choices are prerequisites for designing steps towards sustainable behavior. This article explores, for the first time, the educational value of personal Footprint calculators and their contribution in terms of enhancing awareness of the environmental consequences of consumption behaviors. Our study involved the application of Global Footprint Networks' personal Ecological Footprint (EF) calculator in teaching aimed at High School and postgraduate University students in two geographical areas (Italy and UK). Students calculated their individual EF, and used the results to explore the environmental consequences of their current consumption behaviors and the effects associated with selected changes in daily consumption activities. Our analysis shows that students were able to appreciate the difference between their individual Footprints and national and global averages. The calculator also enabled them to debate sustainable consumption in the context of their everyday life, inducing them to personally experience the multidimensional character of sustainability. Students finally demonstrated an ability to quantitatively capture how knowledge and awareness of the environmental consequences associated with certain consumption behaviors may facilitate better choices, and encourage greater commitment to sustainable resource use.

Keywords: Education for sustainability, personal Footprint calculator, teaching sustainability, sustainable consumption, environmental awareness.

1. Introduction

Education has gained a central role in the transition to a sustainable world since the Stockholm Conference in 1972, which recognized the importance of education in fostering environmental protection and conservation. Since then, Article 36 of Agenda 21 (UNCED, 1992) has called for reorienting education towards sustainable development and the UN has launched one of its most important initiatives – the Decade of Education for Sustainable Development (DESDE) 2005-2014 (UN, 2002) – as well as its follow-up Global Action Programme on Education for Sustainable Development (UNESCO, 2014a). More recently, within the UN Sustainable Development Goals (SDGs) initiative, education has been linked with 16 of the 17 SDGs (Vladimirova and Le Blanc, 2015), and sustainable, equitable education has been made a core objective of SDG target 4.7 (UN, 2015).

Education can affect many spheres of life, as it represents a major driver of development (Jorgensen et al., 2015; UNESCO, 2014b) and contributes to inequality reduction[1]. Universities can play a role in achieving a more sustainable future (Barth and Rieckmann, 2012; Cortese, 2003) as they can contribute to developing competences through education (Larson and Holmberg, 2017; Wals, 2014). In terms of promoting sustainable development principles, Leal Filho et al., (2016) argue that Universities should become a change agent for society, given the large periods of time spent in education by millions of young people, as well as adults (UNESCO, 2007).

According to a definition provided by UNESCO (2007), Education for Sustainable Development "prepares people to cope with and find solutions to problems that threaten the sustainability of the planet". As such, Education for Sustainable Development is applicable to all higher education programmes, not only environmental ones, as sustainable development is considered one of the most crucial challenges of humanity in the 21st century (Jones et al., 2008; Mintz and Tal, 2014; Orr and Sterling, 2001).

Sustainability in Education is rooted in the field of Environmental Education with approaches ranging from nature-based learning to critical pedagogy and responsible environmental behavior, up to issue-based inquiry and systems thinking. Compared to Environmental Education, Sustainability Education creates a more complex agenda, expanding the subject to be considered beyond the environment to include social, cultural and economic concerns such as inequalities and global poverty (Evans et al., 2017; Holm et al., 2016). It thus aims at promoting sustainable behavior (in one's own life), transferring the necessary knowledge for the transition to a sustainable society, and creating the professional attitude necessary to address challenges (Stough et al., 2017). As acknowledged by Hugé et al. (2016), Higher Education Institutions have always been key actors for societal changing, and in the case of sustainable development, teachers and researchers have a role to pave the way towards a sustainable future. However, despite initiatives across the globe and international declarations to guide the integration of sustainability within the institutional dimension, a transition towards a sustainable University has still to be reached (Lozano et al., 2014). According to Sidiropoulos (2014): "sustainability is a learning journey and each educational intervention contributes towards building greater understanding and orientation towards sustainability".

Teaching sustainability can benefit from the use of both qualitative and quantitative tools and indicators (Kapitulčinová et al., 2017). Alongside providing theoretical knowledge, they can support those teaching and those being taught connecting themselves, their daily activities – and in general their behaviors – with the wider sustainability challenge (Fernández et al., 2016; Lambrechts and Liedekerke, 2014).

Over the last two decades, many indicators and tools have been proposed by different actors (Moreno Pires, 2014) to help society better understand the environmental consequences of their activities. This has been referred to as the "spreading indicator culture" (e.g., Pulselli et al., 2016; Riley, 2001). While the primary goal of most of these indicators has been to inform and support policy making, some have also gained public attention due to their immediateness and the simplicity of their message. Among these indicators and tools is the Ecological Footprint (hereafter EF), which has gained a prominent

[1]In this regard see http://www.un.org/sustainabledevelopment/education/

position in the sustainability debate since its introduction in the 1990's (Rees, 1992, 1996; Wackernagel et al., 1999).

The history of the EF as a tool and its value has not been exempt from criticism, as indeed its methodology and policy usefulness have been deeply scrutinized by the scientific community (e.g., Costanza, 2000; Galli et al., 2016; Giampietro and Saltelli, 2014a,b; Goldfinger et al., 2014; Kitzes et al., 2009; Lin et al., 2015; van den Bergh and Grazi, 2015). However, while the policy usefulness of the EF as a tool is yet to be fully identified (Collins and Flynn 2015; Galli, 2015a; van den Bergh and Grazi, 2013; Wiedmann and Barrett, 2010), agreement exists on its communication value: it has helped re-opening a global sustainability debate by communicating the scale and significance of humanity's overuse of the Earth's natural resources and ecosystem services in simple and powerful terms (e.g. Collins and Flynn, 2015; Fernández et al., 2016; Wiedmann and Barrett, 2010).

The EF is frequently used by NGOs to illustrate and inform different audiences about sustainable development, both globally and locally. For instance, WWF International has used the EF in its bi-annual flagship publication - the *Living Planet Report* - since 2000, and in the 2016 edition of this report (WWF et al., 2016), it indicated that the equivalent biocapacity of 1.6 Earths was needed to provide the natural resources and services humanity consumed in 2012. The NGO Emirates Wildlife Society in the United Arab Emirates (UAE) has used the EF to develop its *Heroes of the UAE* campaign[2] and identify stakeholder groups to be targeted by such a campaign (Abdullatif and Alam, 2011). The NGO Global Footprint Network (the partner network for the global EF community) - in cooperation with the New Economics Foundation and WWF - has been promoting the Earth Overshoot Day[3] (EOD) global campaign since 2006[4], in an attempt to interact with different audiences and communicate the scale of change required to live within the earth's ecological limits (Collins and Flynn, 2015)[5].

Alongside global and national level applications (e.g., Borucke et al., 2013; Coscieme et al., 2016; Galli et al., 2014; Kitzes et al., 2008), the EF has also been applied at regional (e.g., Bagliani et al., 2008; Galli et al., 2015; Hopton and White, 2012), city (e.g., Baabou et al., 2017; Moore et al., 2013), and corporate levels (e.g., Bagliani and Martini, 2012), dealing with topics ranging from wider sustainability, to carrying capacity and natural capital management, and specific sectoral issues (e.g., Bastianoni et al., 2013; Collins and Flynn, 2015; Fang et al., 2016; Galli, 2015b; Patterson et al., 2007). More recently, the application of the EF to education establishments has received increasing attention in the academic literature, with studies measuring the EF of Universities, Tertiary Colleges and High Schools in Australia (Flint, 2001), Belgium (Lambrechts and Van Liedekerke, 2014), Canada (Burgess and Lai, 2006), China (Li et al., 2008), Israel (Gottlieb et al., 2012), Portugal (Nunes et al., 2013), Spain (Fernández et al., 2016), Turkey (Südaş and Özeltürkay, 2015), United Kingdom (Wright et al., 2009) and United States (Janis 2007; Klein-Banai and Theis 2011; Venetoulis, 2001). The majority of these studies have tended to focus

[2] http://uae.panda.org/ews_wwf/achievements/heroesoftheuae_achievement/

[3] EOD marks the date when humanity's demand for ecological resources and services in a given year exceeds what Earth can regenerate in that year. The first date human consumption exceeded the earth's available biocapacity for a given year, was 29 December 1970 while in 2016, EOD was August 8th with the remainder of the year corresponding to global overshoot: humans started to deplete resource stocks from the land and oceans, and accumulate increasing amounts of carbon dioxide in the atmosphere and oceans.

[4] For more information, please visit http://www.overshootday.org/

[5] In 2016, the EOD website received almost 200,000 visitors as well as extensive media coverage, and almost 2 million people used the Global Footprint Network's personal Ecological Footprint calculator.

on measuring the resource use of students, staff and faculties (e.g., Gottlieb et al., 2012; Lambrechts and Liedekerke, 2014). Although different methodologies and EF calculators have been used in these studies, the majority of them found energy use and mobility to be significant contributors to the size of Universities' EFs (see Nunes et al., 2013).

A smaller number of studies have focused on the use of the EF to develop scenarios to examine how recent and potential changes may influence the scale of an institution's Footprint, for example, an increase in recycling levels or sourcing energy from renewables (see for example, Conway et al., 2008; Lambrechts and Liedekerke, 2014). Fernández et al., (2016) recognize that despite its limitations, the EF is a valuable tool for engaging students due to its ability to convert personal behaviors into quantitative data. For this reason, they have used the EF as tool to deliver a training programme on sustainability to 119 alumni at the *Universitat Internacional de Catalunia* (UIC) who were planning to become Elementary School teachers. One of the main outcomes of this training has been the change of alumni consumption patterns. However, opposite trends have been identified by other studies (e.g., Barrett et al., 2004; Brook, 2011) in which students did not substantially change their consumption behavior despite becoming more aware of their own responsibility.

Despite existing studies, a focus on the EF of students at an individual level and an assessment of the educational value of calculating their EF has yet to be undertaken. The translation of EF stimuli into measures and effective behavior that orient the transition towards a sustainable society is a difficult task; however, the systemic view provided by the EF indicator and an appropriate disaggregation of the elements of such an approach may help identify the main components which a project of cultural progress can be based upon.

As such, this paper aims to address this research gap by using a personal Footprint calculator to measure students EF at two European Universities. This paper specifically focuses on answering the following research questions:

- What size are students' EFs? Do differences exist between students within and between institutions, and across programmes? And what factors may be influencing the scale of student EFs?
- What types of change are students prepared to make in order to reduce their individual EF? And to what extent are they able to reduce their EF?
- How valuable do students perceive the EF calculator as a tool for understanding the environmental consequences of resource use? And how can EF calculators be developed further to enhance the student learning experience?

2. Case Study

This paper focuses on two European Universities that have actively engaged with the EF to deliver their teaching curriculum: Cardiff University (UK) and University of Siena (Italy). Both Universities have conducted research on the EF since 2002, and have used the Footprint in their students learning and teaching.

Cardiff University is a public research university founded in 1883, and a member of the UK Russell Group of Universities which is widely considered as representing the best universities in the country. At Cardiff, the School of Geography and Planning has used the EF as part of its teaching on several modules at undergraduate and postgraduate level. These modules focus on subjects related to environmental policy and management, sustainability, mobility and tourism, international studies and research methods.

The University of Siena is one of Europe's oldest public universities, founded in 1240. It is a signatory of the Commitment on Sustainable Practices of Higher Education Institutions promoted within the UN Conference on Sustainable Development in Rio; it hosts the Mediterranean regional hub of the UN Sustainable Development Solution Network (UN SDSN); and is a member of the Italian Network of Universities promoting Sustainable Development (RUS)[6]. At Siena, the Ecodynamics Group has used the EF as part of its teaching within a trans-disciplinary Sustainability course for all students and employees of the Athenaeum, and public stakeholders.

The sample of students from Cardiff University studied for one of the following three postgraduate programmes: *Sustainability, Planning and Environmental Policy* (SPEP); *European Spatial Planning and Environmental Policy* (ESPEP); and *Food, Space and Society* (FSS). The SPEP postgraduate programme focuses on issues and concepts underpinning key sustainability challenges, governance and planning solutions used in policy, business and activism. The SPEP program is taken by students on a full-time or part-time basis (FTSPEP and PTSPEP, respectively). ESPEP is a joint ERASMUS Masters Programme involving three European Universities (Radboud University Nijmegan in The Netherlands, Blekinge Institute of Technology in Sweden and Cardiff University in Wales) which focuses on the influence of European and international development on space, the environment and economy, and large spatial challenges such as climate change. FSS focuses on food related issues, and policy and practical solutions to key challenges in the food system. Students across all three programmes complete a core 'Researching Sustainability' module which focuses on a range of research methods that can be used to investigate topics related to sustainability, one of which includes the EF.

The sample of students from the University of Siena were High School students attending University apprenticeship schemes. Apprenticeships at Siena are designed to inform students about the academic educational offer as well as to provide them with a first insight into the environmental consequences of their consumption behavior. Students attending apprenticeships came from third year of Technical High School (TCHSIII) and third and fifth year of Scientific High School (SCHSIII and SCHSV, respectively). Technical High School focuses on the laboratorial teaching joined to the traditional educational science. This High School has been designed to fill the gap between theoretical sciences and new technologies and to foster students towards scientific university degrees. Scientific High School provides a general education based on the balance between the linguistic, literary and philosophical culture, and the acquisition of scientific knowledge and methodologies for their investigation.

3. The Ecological Footprint: an overview

3.1 Resource accounting within the Ecological Footprint

[6] Rete delle Università per lo Sviluppo Sostenibile: https://www.crui.it/rus-rete-delle-universita-per-la-sostenibilita.html

EF accounting tracks human demand on, and natures supply of, life-supporting resource provisioning (e.g. food resources, fibers, etc.), and one regulating ecosystem service (i.e., climate stabilization through carbon sequestration) through the use of two metrics: the EF and *biocapacity* (Borucke et al., 2013; Galli et al., 2014). Both metrics are expressed in hectare-equivalent units, or global hectares (gha), which represent productivity-weighted hectares (Galli, 2015a) and allow the two metrics to be compared to derive ecological balances (Galli, 2015b; Monfreda et al., 2004).

Borucke et al., (2013) constitutes one of the most comprehensive descriptions of the EF accounting methodology, especially at national level. However, to clearly explain the approach used in this study, and the type of results it yielded, three main characteristics of national level EF accounting should be highlighted:

1) National Footprint Accounts (NFAs) use a consumer approach, thus quantifying the hectare-equivalent amounts appropriated by nations' residents because of their final net consumption activities (Borucke et al., 2013);
2) Through the Consumption Land-Use Matrix (CLUM), national EF results can be broken down by land components and consumption categories (GFN, 2009; Galli et al., 2017): the first set of results shows the type of land (i.e., cropland, grazing land, forests, fishing grounds, carbon uptake land – or simply carbon Footprint – and built up surfaces) humans appropriate while the latter indicates the major consumption categories causing such appropriation (e.g., food, shelter, mobility, goods and services).
3) NFAs by consumption categories can be geographically scaled to derive the EF at the household level for a given region, province, city or urban agglomeration (Baabou et al., 2017). They constitute the starting point from which students in this study calculated their individual EF (see section 3.2).

As summarized by Baabou et al., (2017), EF applications at a geo-political level below the national level follow either a *top-down* (compound) or a *bottom-up* (component) approach (Moore et al., 2013; Wilson and Grant, 2009). In the former case, national EF results are scaled to the sub-national or individual level (e.g. a student) by means of household expenditure data or individual data, respectively. In the latter, sub-national or individual EF values are calculated by adding together the Footprint for each commodity consumed by the subject of the study, which must be thoroughly scrutinized. Although likely to be more accurate, this method is resource and data intensive, and often requires longer execution time due to data unavailability; furthermore, it does not easily allow comparison between subjects due to different data sources and assumptions within the calculation (Baabou et al., 2017; Lambrechts and Liedekerke, 2014; Nunes et al., 2013). The top-down approach is usually at the base of any EF calculator.

3.2 Selection of Ecological Footprint calculator

Many EF calculators are available on the web, each with its strengths and weaknesses. Reviews of EF calculators are provided by Collins and Flynn (2015) and Fernández et al., (2016); these reviews found the calculators provided by Global Footprint Network (GFN) and Redefining Progress (RP) to be the most comprehensive. While Fernández et al., (2016) opted for the use of the calculator provided by RP, in line with Collins and Flynn (2015), GFN's personal EF calculator was used in this study as it was considered more informative[7], user friendly, freely available and consistent with the most commonly used NFAs. At the time of writing this paper, this calculator was available for 15 countries (although with varying levels of resolution), one region and one city.

GFN's on-line EF calculator uses a top-down approach, and also enables students from both institutions to select the same country when calculating their EF, thereby enabling comparability of results. It also allows users to explore up to five *'what if'* scenarios to reduce their Footprint. Although this EF calculator doesn't aim to provide accurate EF results for individual students, it should be highlighted that the primary purpose of this study was to explore and discuss the usefulness of the EF calculator in raising awareness of sustainability and integrating it within the higher education teaching.

The calculator contains questions based around five consumption categories: *Food*, *Housing* (which includes shelter and energy use), *Mobility*, *Goods* and *Services* (see Figure 1). Users of the calculator have the option to answer 18 basic questions, or 25 detailed questions thereby providing more accurate Footprint results (see Appendix 1). In both cases, the majority of calculator questions include scale responses, for example '*Never'* through to '*Often'* or '*A few*' through to '*A lot*'. Questions relating to *Mobility* and *Shelter* are the most detailed. Although Gottlieb et al., (2012) highlight that the use of specific questions with scaled responses may not be as precise as asking the user for specific amounts, it does make calculators more accessible to a wide range of potential users with different abilities and levels of understanding. Moreover, it is a consequence of GFN's calculator using a top-down compound method (see section 3.1) to derive the user's Footprint from a national benchmark value.

In terms of reporting individuals' EF results, GFN's calculator presents them in several ways: number of Planet Earths, number of global hectares by land components and percentage contribution for each consumption category (see bottom-left screen-shot in Figure 1).

[7] The calculator webpage http://www.footprintnetwork.org/en/index.php/GFN/page/calculators/ provide answers to thirteen 'frequently asked questions'.

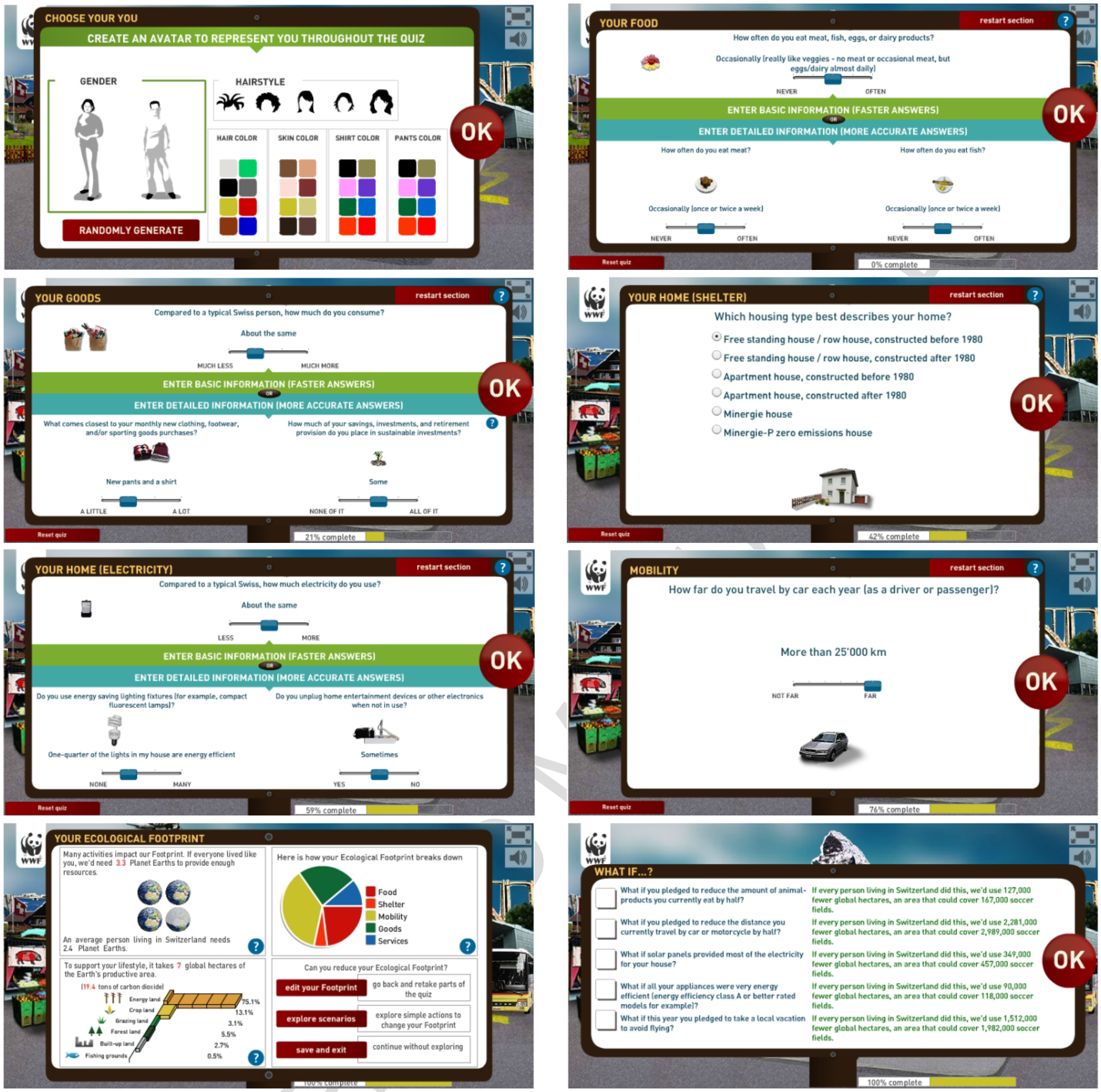

Figure 1: Screenshots of sections within Global Footprint Network's personal Footprint calculator.

4. Methodology: measuring Students' Ecological Footprint using the Personal Footprint calculator

Prior to calculating their EF, students at Cardiff and Siena received teaching that included an introduction to the EF, how it is measured, and its strengths and limitations as a sustainability indicator. To ensure a consistent application of the EF calculator and interpretation of the results, a member of the research team was involved in developing the teaching material used by both institutions.

Students voluntarily calculated their personal EF as part of an interactive teaching session which involved using desktop computers and lasted approximately 2 hours. In Cardiff, one teaching session was held with 20 students, in Siena three sessions were held with 5, 11 and 15 students, respectively. At both institutions, students were introduced to the calculator and given specific instructions on how to take account of their consumption activities when answering the relevant calculator questions. Within the calculator, Switzerland was selected as students home country as specific calculators were not available for the UK and Italy, and would also enable comparability of results. Students were also asked to answer questions in relation to the current calendar year and not just term time. This was to ensure that all international travel and holidays abroad were taken into account. If students had changed their place of accommodation during the last 12 months, they were asked to consider their current accommodation. In situations where students were unsure of the correct answer (e.g., *how many liters of fuel does your car use per 100 km?*), they had three options: 1) use the average result on the scale provided within the calculator, 2) request the advice of the lecturer to derive an estimate (e.g., with information on the car model estimate fuel consumption), 3) phone a family member (this was the case for High School students in Siena).

The process used to calculate students baseline EF, potential EF reductions, and initiate discussion on the value of the calculator consisted of 5 key stages:

Stage 1: students were asked to complete a first round of their EF calculation using the on-line calculator. Results for individual students were then uploaded onto Google Sheets, ranked from highest to lowest, and presented to each group of students.

Stage 2: an interactive class discussion followed, where students were asked to reflect on their individual EF results and the scale of their pressure on the planet (e.g., their contribution to the global overshoot). Students were also asked to consider a number of specific questions: "*how many planets are required to support your current lifestyle?*", "*are you surprised by the size of your Footprint?*", "*how does it compare to your friends?*", "*which consumption category has the largest influence on your Footprint?*" and "*what activities might be contributing to this?*"

Stage 3: students were then asked to consider ways in which they could reduce their individual EF (i.e., eat less meat, travel less by car, etc), and edit their responses to relevant questions within the calculator, and recalculate their EF. Recalculated EF and potential reductions were uploaded again onto Google Sheets and ranked for presentation to each group of students.

Stage 4: a second interactive discussion with students was held to explore the types of changes required to make the transition to a sustainable lifestyle versus those they would be prepared to adopt. Students were also asked to consider whether they were surprised by the extent to which they could reduce their EF. This discussion was used to reflect on the set of criteria one has to consider when dealing with the sustainability challenge (i.e. sustainability as a multi-dimensional concept).

Stage 5: the final stage involved students discussing the usefulness of the EF calculator and ways in which it could be improved and developed further.

Although a standardized and systematic way to conduct this experiment does not exist yet, the exercise was the same for all Cardiff and Siena students and represents a good basis for introducing concepts and knowledge – especially in the field of environmental sciences – in an interactive teaching way. As acknowledged by Dielman and Huising (2006), the use of game is essential in Education for Sustainability as it can foster understanding in concrete organizational setting. In particular, the questions and possible answers enabled the introduction of terms that some students were unaware of, such as bike sharing, car pooling, or passive house; also questions on the dimension of their own house and the type of heating system stimulate curiosity and discussion.

5. Results

5.1 Results overview

Footprint calculations were undertaken by 51 students across both institutions: 20 in Cardiff (39%) and 31 in Siena (61%). In Cardiff, students were from three postgraduate programmes (SPEP; FSS and ESPEP), of which 55% were female and 45% male. In Siena, students were from different curricula (scientific - S and technical - T) and years of High School (third: SCHSIII and TCHSIII; fifth: SCHSV), of which 74% were male and 26% female. Table 1 provides a summary of the average, minimum and maximum EF per capita (i.e. student) across programmes at each institution.

Table 1: Average, minimum and maximum Ecological Footprint values, by student programme.

Institution		Round 1			Round 2			Footprint Reduction	Sample size (# students)
	Programme	Av. EF (gha/cap)	Min. EF (gha/cap)	Max. EF (gha/cap)	Av. EF (gha/cap)	Min. EF (gha/cap)	Max. EF (gha/cap)	Av. EF (%)	
Cardiff University	FTSPEP	4.2	3.7	4.7	3.7	3.2	4.4	11%	5
	PTSPEP	6.1	5.7	6.9	4.8	4.0	6.3	21%	3
	FSS	4.0	3.2	4.8	3.0	2.6	3.3	24%	3
	ESPEP	4.2	3.2	5.1	3.3	2.5	4.6	22%	9
University of Siena	SCHSIII	4.8	3.7	6.9	3.9	2.9	5.5	18%	11
	TCHSIII	5.6	2.6	8.3	4.6	2.8	8.3	19%	15
	SCHSV	5.9	5.1	7.7	5.0	4.1	5.9	15%	5
Students Average	-	5.0	3.9	6.3	4.1	3.2	5.5	19%	-

Legend: FTSPEP= Full-time Master student of *Sustainability, Planning and Environmental Policy* ; PTSPEP= Part-time Master student of *Sustainability, Planning and Environmental Policy* ; FSS= *Food, Space and Society ;* ESPEP= *European Spatial Planning and Environmental Policy; SCHSIII= third year of Scientific High School; TCHSIII= third year of Technical High School; SCHSV= fifth year of Scientific High School. Average values for the whole sample are reported at the bottom of the table.*

Results from the first round of calculations show that the average EF per capita ranged from 4.0 to 6.1 gha. This is higher than the world average EF per capita (2.8 gha) (GFN, 2016), and indicates a higher level of consumption compared to the world average. As shown in Figure 2, students' EF was also higher than the average per capita globally available biocapacity (1.7 gha) (GFN, 2016).

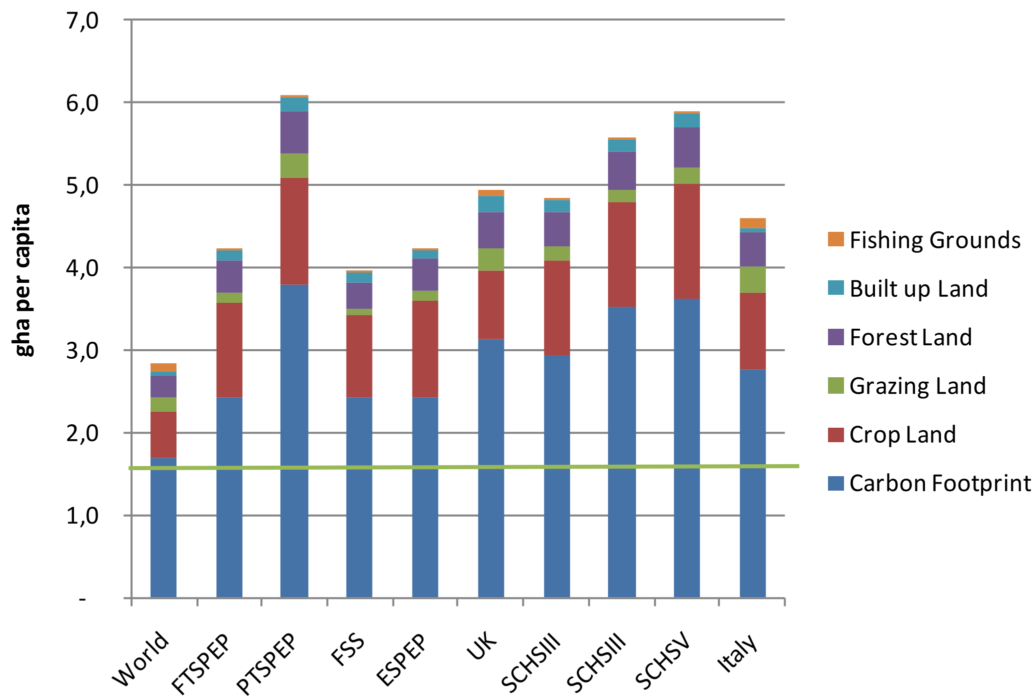

Figure 2: Ecological Footprint of students by land components - first calculator round. Average per capita Footprint values for the World, UK and Italy are also reported for comparison purposes. Green line represents the average per-capita globally available biocapacity (1.7 gha).

With the exception of PTSPEP students, the per capita EF for postgraduate students was lower than that for High School students. When comparing the EF of students with their country average per capita EF, it was found that the average EF for High School students' in Siena was higher than the national per capita average, whereas the opposite was found for students in Cardiff (the exception being part time SPEP students). Moreover, the gap between the minimum and maximum value of per capita EF was found to be consistently larger for Siena students, suggesting lower knowledge and awareness on the topics and issues connected to the EF calculation.

To understand the factors that may drive the scale of students' EF, a breadown of their EF by land component was necessary. As shown in Figure 2, the *carbon Footprint* component was found to account for the largest proportion of students EF in Cardiff (ranging from 57% to 62% of the total, depending on the student programme) and Siena (from 61% to 63%). This reflects respective national and world average trends. However, in the case of students at Cardiff University, this component was lower (except for FTSPEP and PTSPEP students) than the UK average (64%). In the case of Siena students, the result was the opposite with carbon representing approximately 60% of Italy's overall EF. *Crop land* was found to be the second most demanded land component amongst both group of students (ranging from 22% to 28%), reporting higher per capita values in respect to both world average (20%) and their originating countries (17% in UK and 20% in Italy). *Forest land* was found to be the third most demanded component (ranging from 8% to 9%), in line with the world average and students' originating countries. The *Built-up land component* was the lowest contributor to the EF results obtained in both Universities (about 3% of the total), similar to that found by Fernández et al. (2016) of students at Catalunia International University.

5.2 Reducing students personal Ecological Footprint

During the first round of EF calculations, the *Food* category was found to be the largest driver of the EF (an average of 40%) across all student groups (Figure 3). This is in line with recently published studies dealing with EF evaluations of students (i.e. Fernández et al., 2016; Gottlieb et al., 2012). The lowest *Food* Footprint share was obtained by FSS students (35% of the total EF value), highlighting a nexus between knowledge and low impacts (Song et al., 2015). Conversely students from High School still live with their parents and may not perceive the responsibility of their choices yet. The *Goods, Services* and *Mobility* categories were also key drivers (22%, 17% and 13% respectively, on average) for postgraduate and High School students EF. The EFs of *Goods* and *Services* were higher for postgraduate students, while *Mobility* was higher for High School students. These differences may be due to student age and sociological context. Postgraduate students tend to be economically autonomous; on the other hand, High School students in Siena use money especially to travel to school and the city center with motor-scooters and publictransport. *Shelter* (which includes housing and energy) was the category with the lowest contribution to students EF (9% on average), and this consumption category was found to be one where students didn't have direct influence: in Cardiff they inhabit shared student accommodation or private rented houses, while High School students tend to live with their parents.

As previously discussed in Section 4, students were asked as part of Stage 4 to explore the types of changes required to make the transition to a sustainable lifestyle. By comparing the EF results from the two rounds of the calculator exercise, it was observed that all student groups were on average able to reduce their EF by 19% (see Table 1 and Figure 3), with average reductions for postgraduate and High School student groups being 20% and 17%, respectively. This demonstrated that students could identify possible changes in their day to day consumption habits after receiving the educational message from the first round. As shown in Table 1, the highest EF reduction was observed for FSS students (-24%), whereas FTSPEP students were only able to reduce their EF by 11%. High School students in Siena achieved EF reductions that ranged from 15% to 19%.

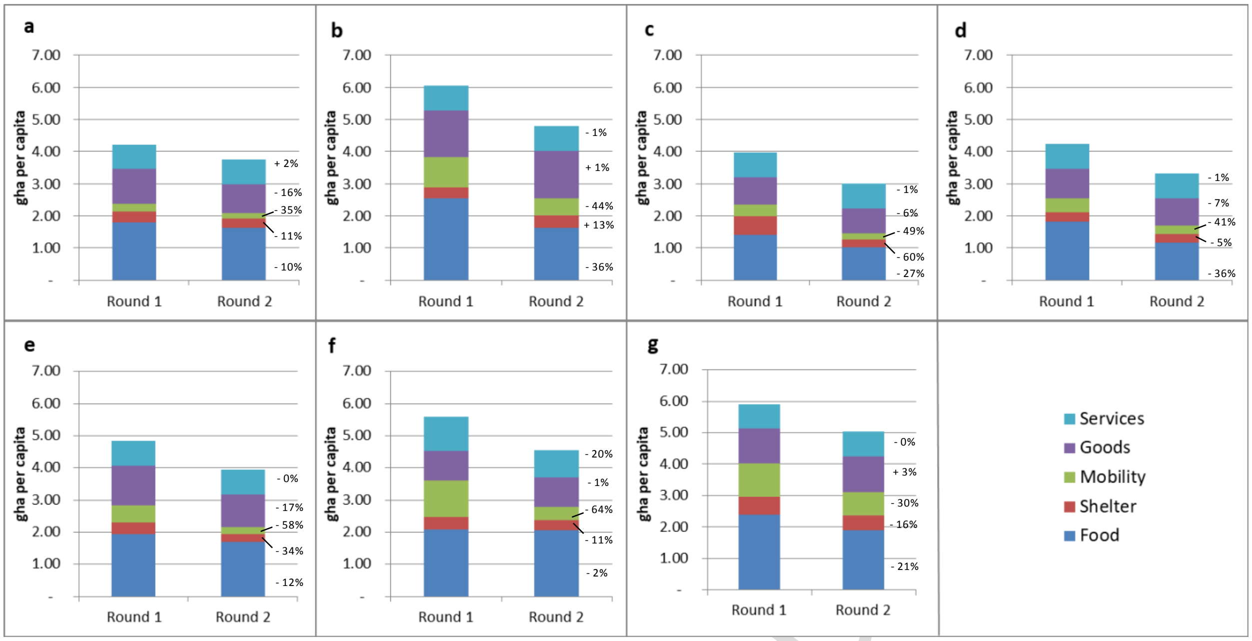

Figure 3: Ecological Footprint of students, by classes (a for Full-time Master student of Sustainability, Planning and Environmental Policy; b for Part-time Master student of Sustainability, Planning and Environmental Policy, c for Food, Space and Society, d for European Spatial Planning and Environmental Policy, e for third year of Scientific High School; f for third year of Technical High School and g for fifth year of Scientific High School) and consumption categories: comparison between the first and second round of the calculator. Values next to the "Round 2" column indicate the percentage variation obtained per consumption category.

With the exception of FSS students (Figure 3c), who mainly focused on reducing the EF of Shelter (e.g. by altering the type and amount of energy consumed at home), all other student groups focused on *Mobility*, especially High School students (Figure 3e, 3f and 3g), who reduced this component of their EF from 30% (SCHSV) (see Figure 3g) to 64% (TCHSIII) (see Figure 3f). *Food* was the second most important category on which reduction efforts were concentrated, although High School students chose not to focus their reduction priorities in this way. However, third year High School students were able to reduce the EF associated with their consumption of *Goods* and *Services* more than any other student groups (Figure 3e and 3f).

It should however be acknowledged that these results only relate to students preferred behavior changes and not their actual changes. As claimed by Lozano and Young (2013), how to assess changes on students' personal life inspired by "sustainability education" programmes is still a challenge. Although the results show different predisposition and behaviors between the student groups, the sample used in this study is relatively small and so does not allow for any statistical analysis. Comparison with published studies is also limited as there are few similar experiences and results to draw comparisons: while most studies assess the EF of a campus or students during term time only, this study focuses on the EF of individual students over one calendar year. To strengthen the efficacy of lessons learnt from the application of EF calculators, a wider and systematic repetition of the experience could be a valuable focus of future research, possibly differentiating results by country, age, gender, educational level and teaching curriculum.

5.3 Students' reflections on the value of the Footprint calculator.

Stage 5 of the process involved obtaining students views and opinions on the value and potential limitations of the EF calculator. Overall, the majority of students perceived the EF calculator to be user-friendly with easy to answer questions relating to their consumption behaviors. Furthermore, the way in which the calculator presented their EF results enabled students to fully appreciate the scale of impact associated with their consumption behavior[8]. The use of the EF calculator can thus be considered as an operationalization of the "learning by doing" paradigm, which implements the theory of "experimental learning" (Kolb, 1984) by applying games as education for Sustainable Development tools (Dielman and Huising, 2006).

A number of students also identified some limitations associated with the EF calculator. These included: a limited number of questions for some consumption categories (e.g. energy use at home and food); and, an absence of specific questions relating to holidays, their school or University. International postgraduate students at Cardiff also highlighted that the calculator only contained a limited range of countries for students to calculate their EF. A further limitation related to the calculators' inability to take account of the effect of substitutes. For example, reducing the purchase of magazines and books, but not accounting for an increase in energy use due to reading articles on a computer.

6. Discussions and Conclusions

This paper explored the use of the EF and GFN's personal Footprint calculator at two European Universities as an approach to teaching environmental aspects of sustainability, and engaging students in discussion about resource use implications. Although the analysis did not focus on students' individual EF results, it did highlight that none of the students had a EF at or below the average per-capita globally available biocapacity (1.7 gha).

On the basis of the first round of EF results (see stage 2 in section 4), a discussion was initiated on the key factors (e.g., consumption activities) that influence the scale of the Footprint as well as the type of lifestyle changes students would be prepared to make in order to reduce their Footprint.The majority of postgraduate students at Cardiff were not surprised that their food consumption patterns had the most significant impact due to their diets, in many cases low in local organic products and heavy on meat consumption. Conversely, this realization was surprising for High School students in Siena. Moreover, a few students were surprised that vegetarian and vegan diets have an associated EF. As highlighted by Galli et al. (2017) crop land is required to grow vegetables and energy inputs are needed to process and distribute them. Students from both institutions also reflected on the fact that food consumption is a basic human need and is difficult to change: a lot of food nowadays available on the market is conventional (as opposed to organic), imported (as opposed to local), highly processed and packaged

[8] A student stated "*It really showcases how an individuals lifestyle choices can significantly affect their environmental impact*". Another added "*It makes you question yourself about aspects you did not know were causing a serious effect. It covers almost every relevant area*".

(e.g., ready-to-eat meals) and thus a radical change in food supply chains would be required by institutions to reduce this.

Although *Mobility* and *Housing* (both shelter and energy use) made a less significant contribution (after *Food*) to the majority of students' Footprints, they were among the most debated activities by students at both institutions. These were identified as areas in which noticeable interventions would be needed by government institutions to improve the efficiency of existing infrastructures (e.g., inefficient buildings and urban design, as well as public transport services being limited). Postgraduate students at Cardiff also reflected on the energy mix in the UK, which is currently characterised by a low share of renewables.

Regarding consumption of *Goods,* only postgraduate students at Cardiff recognized the influence of market and peer pressures to follow current fashion and technology trends thus encouraging increasing trends towards conspicuous consumption. Finally, students at both institutions had similar EF results for the *Service* category, and observed they were unable to influence this aspect of their day-to-day life. This is due to the fact that most Footprint calculators (including the one used in this study) do not ask specific questions in relation to service use, but assume an equal use of services among the residents of a country (and thus an equal share of the Footprint associated with it).

When students were asked about the changes they would be prepared to make, convenience and cost (especially for students who support themselves financially) were key factors in determining both the type and extent of change. However, it is acknowledged that the number and range of questions contained within the various sections of the calculator (see Appendix 1) may have influenced students' responses. Moreover, for aspects of day-to-day life, students showed contrasting views on what they would or wouldn't be prepared to commit to almost all areas except *Goods*. A key tendency amongst students was also seen to go for small nudges rather than dramatic lifestyle changes:

- *Food:* almost all students at both Universities acknowledged that changes to their diet would make a significant contribution towards reducing their EF; however, only about half of them were prepared to adopt these changes. Of those ready to commit, the majority were ready to switch to a reduced meat diet and to use less packaged food; however only a few (ESPEP students) were prepared to switch to a vegetarian or vegan diet. On the other hand, many students seemed ready to opt for organic and locally produced food. This latter behavioral change was considered an easier option by students as it wouldn't require a life-style change, just a different means through which to maintain the current food preferences.
- *Goods:* the majority of students did not identify this consumption area as one in which to commitment to reduce their EF, nor as one in which they were prepared to change their behavior. This might be due to the limited number of questions contained within this section of the calculator (see Appendix 1). However, a small number of students at Cardiff did discuss the need to increase recyclable goods and reduce overall consumption of *Goods* as a way to reduce waste production. This was a thoughtful connection made by students, and was not necessarily driven by the calculator.

- *Mobility*: for students, mobility was seen as the most realistic area in which to commit to lifestyle change due to a greater perception of acceptability for change. Nonetheless, students displayed a mix of reactions on their readiness to travel less by plane, with just one student at Cardiff ready to switch to alternatives such as maritime and overland rail. Regarding other forms of travel, a large number of students were prepared to increase their use of public transport and car sharing. However, some reflected on the poor functioning of the public transportation system (i.e., inefficient, unreliable and dirty), which discouraged people from utilizing it. A desire for self-contained communities was expressed by SPEP and ESPEP students at Cardiff (i.e., those which do not require residents to travel as far due to smart planning and closer proximity of services and employment). Working students (i.e. part time) were less inclined to reduce their car travel due to employment location[9].
- *Housing:* for the majority of students (in Cardiff, at least), the type of electricity consumed at home was considered most difficult to change as it depended on energy suppliers. While some students were unable or unprepared to reduce their energy consumption, as it would take a drastic change to really make a difference and reduce their EF, others stated that energy use at home could be more efficient, even in inefficiently-designed houses (e.g., turn off lights, avoid leaving electronic equipments on stand-by, etc). Moreover, students at Cardiff felt less able to commit to changes in the type of accommodation due to their limited accommodation options and the need to share them with other students.

The use of the EF calculator at both Universities has directly and indirectly enhanced students' knowledge and understanding of environmental sustainability and the consequences of unsustainable resource use. It is worth highlighting that, by putting the sustainability debate in the context of their everyday life, as opposed to teaching abstract, intangible theories and concepts relating to sustainable development, students experienced at firsthand – through the calculator exercise – the multidimensional character of sustainability and gained insight as to how the wide array of their daily activities affect the global sustainability discourse[10]. This supports Lozano et al. (2013) claim about the necessity of transdisciplinarity and holistic perspective to incorporate sustainable development concepts into curricula against compartimentalization and reductionism. This is also a prerequisite to foster University towards a better inclusion of sustainability into curricula and thus help students to contribute making society more sustainable (Ferrer-Balas et al., 2010). Moreover, the use of the EF calculator represented a participatory approach to transfer sustainability concepts to students, in line with the claims of Ferrer-Balas et al. (2010).

When asked about the value of the Footprint calculator, students positively reported that it was informative, user friendly and useful in showcasing how an individual's lifestyle choices can significantly affect its environmental impact. Nonetheless, based on the analysis presented in this paper (see section 5.3) and questions asked directly to students regarding possible improvements, there are a number of ways in which the EF calculator could be developed further to enhance their learning. These are:

[9] One student said "*life wouldn't be worth living to me if I didn't travel anywhere ever*".
[10]A student stated "*It makes you question yourself about aspects you did not know where causing a serious effect*". Another added "*Shocked, as you don't realise the impact your consumption habits have on the earth until it is actually in front of you*".

- At the start of the calculator, include an option for students to select their stage in education (i.e., high school or university students); this would enable the calculator to use language that is age appropriate and so assit the user in calculating their EF.
- Increase the number of questions included in the *Goods* section given the relevance of this category to students' Footprint: for example clothing, technology and sports equipment;
- Include questions in the *Food* and *Goods* sections related to reuse and recycling;
- For the presentation of *Mobility* results, differentiate between the contribution of local/national and international travel;
- Extend the range of "*what if"* scenario options to include changes that students have an ability to influence and ensure they are student relevant (this might require the creation of a dedicated student Footprint calculator as opposed to the currently available personal Footprint calculator);
- Within the presentation of the results, add information on the national average EF per capita (and its breakdowns by land component and consumption category) as a benchmark for users;
- In each section, add a "help" button for users to facilitate completing the calculator questions they are less knowledgeable about (e.g. *How many liters of fuel does your motorbike use per 100 km?*)
- Allow changes in Footprint results to be visualized by the user while completing the calculator questions (results are currently visible just at the end of the exercise); similarly allow for such feature when editing/revising your Footprint;
- Increase the number of countries covered by the calculator and ensure that questions reflect the culture and lifestyle of those residing within those countries.

As limited in terms of statistical relevance, the EF findings from this study should not be interpreted as definitive measures of the pressure placed by students on the Earth; nonetheless, the experiment conducted as part of this study is an effective way to initiate participative discussions on environmental sustainability and consequences of human resource use. This study – like many others using sustainability tools and indicators (e.g. emergy evaluation in Almeida et al., 2013) – can be particularly influential if included within educational models as it invites students to reflect on their everyday life, beyond school or university. Furthermore, the EF tool also has the potential to go beyond educating students on the resource use impacts of personal behavior, and enhance professional knowledge and attitudes towards resource use impacts and sustainability in the business environment. This is the core principle behind the concept of Higher Education for Sustainable Development: educate students to foster innovative and sustainable ideas within the society (Lozano et al., 2013; Lozano García et al., 2006; Zilahy and Huising, 2009).

Currently, this study is limited to High School and postgraduate University students and future analyses could take into account undergraduate students. Finally, to take into account the effectiveness of the EF calculator in encouraging actual behavior change amongst students, there is a need for future follow-up studies. For example, longitudinal studies of students EF at the start and end of the same academic year or degree programme.

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562 **Appendix 1:** Summary of questions include in GFN EF calculator. This calculator is accessible at:
563 http://www.footprintnetwork.org/en/index.php/GFN/page/calculators/

Footprint Category	Detailed Questions	Basic Questions
YOUR FOOD	1. How often do you eat meat? 2. How often do you eat fish? 3. How often do you eat eggs/milk/dairy? 4. How much of your diet is based on fresh, unpackaged foods? 5. How much of the food that you eat is locally grown or produced?	FOOD 1. How often do you eat meat, fish, eggs, or diary products? 2. How much of the food you eat is processed or not grown locally?
YOUR GOODS	1. What comes closest to your monthly new clothing, footwear, and/or sport goods purchases? 2. How much of your savings, investments, and retirement provision do you place in sustainable investments?	1. Compared to a typical Swiss person, how much do you consume?
YOUR HOME (SHELTER)	1. Which housing type best describes your home? 2. What is the primary energy source used to heat your house in the winter? 3. What would you say comes closest to the materials your house in constructed with? 4. What is the size of your home? 5. How many people live in your household? 6. Do you heat your hot water with solar energy? 7. To what temperature do you heat your home in winter?	1. Which housing type best describes your home? 2. What is the primary energy source used to heat your house in the winter? 3. What would you say comes closest to the materials your house in constructed with? 4. What is the size of your home? 5. How many people live in your household? 6. Do you heat your hot water with solar energy? 7. To what temperature do you heat your home in winter?

YOUR HOME (ELECTRICITY)	1. Do you use energy saving light fixtures (for examples, compact fluorescent lamps)? 2. Do you unplug home entertainment devices or other electronics when not in use?	1. Compared to a typical Swiss, how much electricity do you use?
MOBILITY	1. How often do you bicycle or walk to get around? 2. How far do you travel by car each year (as a driver or passenger)? 3. How far do you travel by motorbike each year (as a driver or passenger)? 4. How many liters of fuel does your motorbike use per 100km? 5. How many liters of fuel does your car use per 100km? 6. How many liters of fuel does your motorbike use per 100km? 7. What proportion of your car travel indicated earlier takes place within a car sharing scheme? 8. How far do you travel by train each week? 9. How far do you travel by tramway or bus each week? 10. How many hours do you fly each year?	1. How often do you bicycle or walk to get around? 2. How far do you travel by car each year (as a driver or passenger)? 3. How far do you travel by motorbike each year (as a driver or passenger)? 4. How many liters of fuel does your car use per 100km? 5. How many liters of fuel does your motorbike use per 100km? 6. How far do you travel on public transportation each week (train, bus, tramway)? 7. How many hours do you fly each year?

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