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A User-Friendly Tool to Increase Awareness about Impacts of Human Daily Life Activities on Carbon Footprint

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Abstract: In recent decades, climate change has demanded more and more attention. Consumers have the power to influence the carbon footprint of goods and services through their purchasing decisions, but to do this they need to learn more. To address this need, it is necessary to develop online questionnaires able to make people aware of which activities have a greater environmental impact in their daily lives. Focusing on this goal, we formulated two tools for quantifying an individual's carbon footprint over a year. The innovativeness of these tools lies in being user-friendly and providing online open access to compilers, as well as using specific emission factors for the reference context. Specifically, we focused on the main emission sources: gas and electricity consumption, mobility, food, and waste. During these last years, the tools have been proposed to Italian students at different levels of education and to employees of Italian and international companies. The responses from 3260 users revealed an average annual direct carbon footprint per capita of about 5600 kg $CO_{2\text{-eq}}$, which, integrated with the estimate of indirect emissions, provides an estimate in good agreement with the value provided by the Italian National Inventory of greenhouse gases. With the developed tools, people are able to observe which sectors have the greatest impact and consequently are stimulated to emit less by adopting more sustainable behaviors.

Keywords: online tool; greenhouse gas emissions; carbon footprint; individual impact; environmental awareness

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1. Introduction

The carbon footprint can be considered as a subset of the ecological footprint [1]. The latter refers to the biologically productive land and sea area required to sustain a given human population and it is expressed as global hectares [2], where a global hectare is a biologically productive hectare with world average biological productivity for a given year.

In recent decades, the concept of carbon footprint has, however, become common, independent from the ecological footprint. Moreover, the concept of carbon footprint has evolved into a concept in its own right. Following Hammond [3] and the Global Footprint Network [4], a footprint is a spatial indicator, but only a few studies report carbon footprint in terms of global hectares [5,6] to avoid increasing the uncertainty and error derived from the assumptions necessary to convert the CO_2 emissions in an area-based indicator [7]. Therefore, carbon footprint is generally measured in mass units. Indeed, the present form of carbon footprint may be viewed as a hybrid, deriving its name from the ecological footprint, and conceptually being an indicator of CO_2 emissions [1]. Hence, the term commonly called "carbon footprint" should more precisely be called "carbon emission mass" [8].

Even though "carbon footprint" has become a widely used concept and term, there is an open debate on what should be considered to define it. The most important open points concern: (i) which greenhouse gases (GHGs) should be considered (all GHGs, only CO_2, only those that contain carbon, and so on. . .), and (ii) including only direct emissions or direct and indirect emissions together. On the contrary, what a "footprint" is has been more defined. Specifically, it is the climate impact under a specified metric that considers all relevant emission sources, sinks, and storage in both consumption and production within the specified spatial and temporal system boundary [9].

Following Pandey [1], the carbon footprint can be defined as the quantity of greenhouse gases expressed in terms of CO_2 equivalent ($CO_{2\text{-eq}}$) that are directly and indirectly emitted into the atmosphere by an individual, organization, company, process, product (including goods and services), or event within a specified boundary. The set of GHGs and the boundary are defined following the methodology adopted and the objective of carbon footprinting. Despite prevailing differences among the adopted methodologies over the considered period, the $CO_{2\text{-eq}}$ based on 100 years of global warming potential has been accepted as a reporting unit of carbon footprint [10]. Wiedmann and Minx [11] proposed a similar definition to the one proposed by Pandey [1], even though they decided to consider direct and indirect emissions only from CO_2 since the other GHGs were more difficult to quantify because of data availability.

Other terms used in association with or sometimes as synonymous with carbon footprint in the available literature are embodied carbon, carbon content, embedded carbon, carbon flows, virtual carbon, GHG footprint, and climate footprint [9,12–14].

Many companies, organizations, and cities are pursuing "carbon footprint" projects to estimate their contribution to global climate change [15]. These contributions have to be assessed following some of the leading internationally recognised methodologies. Building on a 20-year partnership between the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD), the Greenhouse Gas Protocol [16] works with governments, industry associations, NGOs, businesses, and other organizations [17]. This organization establishes comprehensive global standardized frameworks to measure and manage greenhouse gas emissions from private and public sector operations, value chains, and mitigation actions. In addition to guidelines that give organizations protocols on how to monitor, reduce, and offset their emissions, the Greenhouse Gas Protocol also provides specialized tools for calculating the specific carbon footprint of products and services. Besides the standard provided by the Greenhouse Gas Protocol, there is also the European standard, named Publicly Available Specification (PAS) 2050:2011 [18], which explains how to calculate the carbon footprint of products, identify hotspots, and reduce emissions in the supply chain [19]. PAS 2050 specifies requirements for the assessment of the life cycle GHG emissions of goods and services based on key life cycle assessment techniques and principles. Also, the International Standards Organization has developed a standard for the carbon footprint of products, ISO 14067:2018 [20].

Besides methods that allow assessing the carbon footprint of companies, organizations, cities, products, and services, it is also important to develop methods that allow people to estimate their individual carbon footprint. The knowledge of one's own carbon footprint can help to increase each person's awareness of the problem. However, in this case, the approach must be completely different to that used for companies because the focus should be directed to user-friendly questionnaires that can be filled in within a short time. Moreover, the questions should be easy to answer without asking for information that most people would not be able to provide [21]. The results provided by these carbon footprint calculators have naturally rather low accuracy because there is no way to provide accurate estimations based on the simple questions that can be included in such questionnaires. This is, however, not a critical limitation, as the main goal of these questionnaires is to increase the awareness of people and this goal can be reached even without a great level of accuracy. On the other hand, if these carbon footprint calculators are designed correctly, they can have low accuracy as far as estimations for single users are considered, but they can provide more accurate results for average values over a great number of users.

Many tools are currently available for estimating individual carbon footprint, but none that at the same time are open access, user-friendly, and based on specific emissions factors for Italy. An open-access and user-friendly tool is a software application designed with a focus on simplicity, intuitiveness, and ease of use, allowing users to interact with it efficiently and effectively, even without extensive training or technical knowledge. Moreover, it does not require any license and it features a clear interface, straightforward navigation, and intuitive functionalities, aiming to minimize user frustration and maximize productivity. An example of an individual carbon footprint tool is the one provided for the USA by the Nature Conservancy [22]. Focusing on tools that are available in the Italian language, an interesting tool is the questionnaire proposed by the World Wide Fund for Nature (WWF) for Switzerland [23]. In this questionnaire, there are many questions. All follow the same pattern: a variable number of possible answers, pop-up indications, and a partial result. How the results are presented is interesting in that not only are they shown numerically by how much the emissions increase for each answer, but to make the data more meaningful, the emissions are also expressed in volumes per day. This tool, however, even if available in the Italian language, is not based on Italian emission factors. Another tool that is also available in the Italian language is the one provided by Carbon Footprint Ltd. (England and Wales, UK) [24]. However, this questionnaire has also not been designed specifically for Italy. Moreover, it requires quantitative information on fuel and energy use that is not easy to provide for many people. Despite many existing tools, it is therefore not easy to find open-access and user-friendly tools in the Italian language specifically focused on Italian emission factors. For example, the one developed for the Italian context by the Italian Ca' Foscari University of Venice [25] is not freely available.

Within this context, in order to make people aware of which activities have a greater environmental impact in their daily lives, in 2018 we set up, in cooperation with Vaillant Italia Spa, a tool for estimating individual carbon footprint in the Italian language and specifically dedicated to Italian emission factors. This tool was set up as a web application, the structural layout of which is shown in Table 1. In the following years, we decided to set up a similar tool using the software ZohoForms. An innovative feature of this new tool [26] was that it can be edited and modified by administrators with rather limited background in computer science and it can therefore be easily used within tutorials and internships for environmental sciences students focusing on the topic of carbon emissions accounting. Even though it was focused on the Italian situation, we also provided it in English [27] because of a relevant fraction of Italian international students.

Table 1. Questions and possible answers proposed by the Vaillant web application.

Questions	Answers
Heating	
Geographical area of residence	Northern Italy Central Italy Southern Italy
Type of dwelling	Flat in condominium Single-family house
Number of family members	*
Surface area of the dwelling	*
Period of dwelling construction	Before 1978 Between 1978 and 2005 After 2005
Boiler type	Traditional boiler Condensing boiler

Table 1. *Cont.*

Questions	Answers
Electricity	
Number of LED bulbs	*
Number of energy-saving lamps	*
Number of halogen bulbs	*
Average switching hours per day per bulb	*
Owned household appliances	Air conditioner Washing machine Dryer Electric oven Induction cooker Dishwasher Refrigerator/freezer
Age of appliance	New (less than 5 years) Old (more than 5 years)
Weekly use of appliances (e.g., air condit.)	*
Type of TV set	LCD TV Plasma TV LED TV
Daily TV switch-on	0–3 h 3–6 h More than 6 h
Mobility	
Means of transport used	Car Minivan or camper Van or SUV Motorcycle or scooter Bus Train Plane
Car power supply (if used)	Petrol or hybrid Diesel Methane LPG
Average car passengers (if used)	*
Food	
Type of diet	Rich in meat Balanced Low in meat Vegetarian Vegan
Food consumption by category	Every day Three times a week Once a week
Municipal solid waste	
Degree of separate collection	Compliant Partial Non executed

* Open-ended questions, to be given in numerical format.

The main goal of the carbon footprint tools we set up in the last years was to help people, especially students, understand something more about the GHGs they contribute to emitting. In the process of conceptualizing these tools, our primary focus was therefore directed towards educational objectives rather than solely prioritizing the attainment of precise estimations of carbon footprint. This deliberate emphasis underscores our belief in the paramount importance of cultivating awareness among individuals, particularly students, regarding their environmental impact, rather than solely aiming for impeccably accurate calculations. Consequently, while the tools provide estimations of carbon footprint, specifically in terms of CO_2 equivalent emissions for various sectors, their overarching purpose lies in fostering a deeper understanding and consciousness about the environmental consequences of one's actions.

This paper presents the methodology we used to set up these carbon footprint tools and discusses the results we obtained with them. The analyses highlight that the direct and indirect emissions estimate closely aligns with the value reported by the Italian National Inventory of greenhouse gases.

2. Materials and Methods

The web application and the following ZohoForms tool are based on the same methodology and the same emission factors; the only difference consists in some parts of the questionnaire that have been implemented (and sometimes simplified) in the ZohoForms version to reduce the dropout rate and the time necessary to fill it in.

The methodology we developed for estimating individual carbon footprint focuses on five items: home heating (including also the energy needed to produce warm water and cooking), lighting and appliances, mobility, food, and waste recycling.

2.1. Home Heating

An accurate quantification of the GHG emissions related to home heating would require the type and the amount of fuel used per year. This information cannot, however, be acquired within a questionnaire provided online because most people do not know it. It was therefore necessary to estimate it using data that are easy to provide for them. As far as the type of fuel is concerned, for Italy we could assume that it is natural gas, as home heating is generally based on this fuel [28]. The information that we needed to estimate was, therefore, the amount of natural gas used yearly for home heating. To obtain this estimation, we started from the database used within the software Master Energy System provided by Vaillant Italia [29]. This software allows the estimation of the yearly amount of natural gas necessary for heating an 80 m^2 flat or a 120 m^2 single-family home, considering different levels of thermal insulation (obtained from the period of construction), different climatic conditions (obtained starting from three main Italian climatic areas in the North, Center, and South, and correcting the estimations through the degree days of the Municipality), and different heating systems. In the ZohoForms tool, we started from the data at the basis of the Master Energy System software. They were obtained by more than 400 simulations, focusing on the areas of Milan (northern Italy), Rome (central Italy) and Naples (southern Italy), performed with software for assessing the energy performance of buildings. We then simplified the estimation by considering a standard home obtained by averaging the flat and single-family home values and a standard boiler obtained by averaging the traditional and condensing boiler values. Moreover, we avoided considering the Municipality, asking only for the administrative region and for the altitudinal level. Therefore, we started from a data table providing the natural gas necessary for heating a standard home with a standard boiler in the Milan, Rome, or Naples areas and we then corrected the value provided by this table based on the answers to the following questions:

- What region do you live in?
- Do you live in the plains, hills, or mountains?
- How big is your house? Have you carried out an energy efficiency intervention?

The layout of the section of the ZohoForms tool concerning home heating is shown in Figure 1.

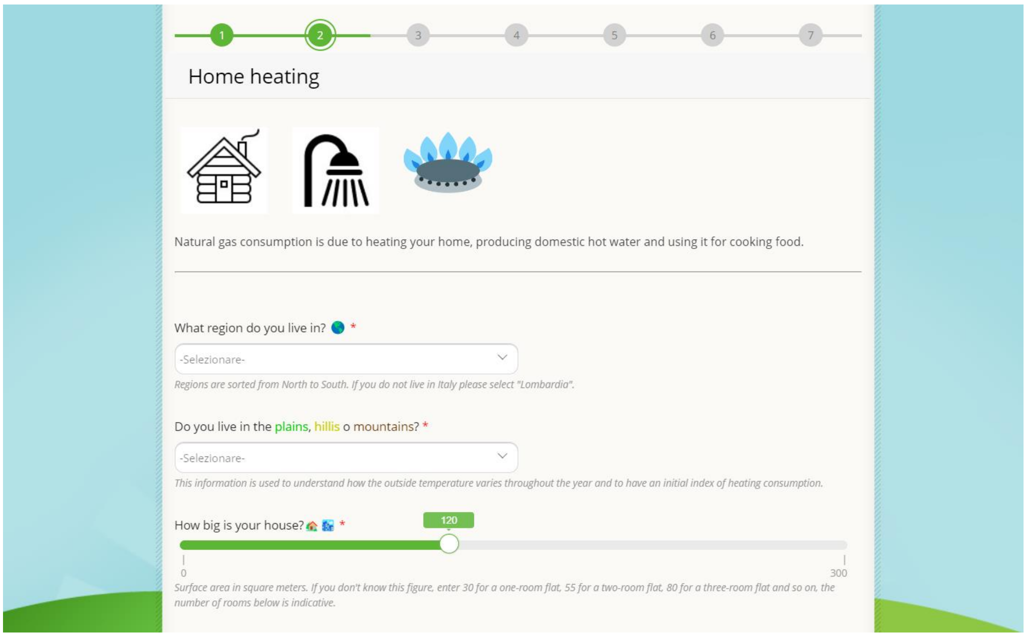


Figure 1. The home heating part of the online tool for the carbon footprint calculator. * Mandatory question to continue with the compilation of the survey.

The answers to the first two questions allowed us to obtain a better estimation of the degree days corresponding to the location of the home of the specific user. We obtained it using a data table of regional heating degree days (for plains, hills, and mountains) that we derived from an updated version of the 30-arc-second monthly 1961–1990 temperature climatologies provided by Brunetti [30]. This dataset allowed us to adapt the values we obtained from the Master Energy System database to the specific area of the user and the climate of the last 20 years. We then used the answer to the last question to adapt the estimation to the considered home. To take into account the surface, we simply considered a linear model, whereas for the energy efficiency interventions (if any), we considered a reduction of 50% in the case of a radical intervention and a reduction of 25% in the case of a partial intervention.

After estimating the natural gas necessary for home heating, we added to it an estimation of the natural gas necessary for producing warm water and cooking, obtained as described by Lombardo [31]. These contributions were then removed from the estimation if the answers to the questions of the section lighting and appliances allowed us to understand that the considered user used electricity for producing warm water or for cooking.

We finally asked the user for the number of persons living in the considered home to share the needed natural gas among these persons.

The natural gas needed yearly by the user was then transformed into $CO_{2\text{-eq}}$ emissions using the emission factor that the Italian Network of Sustainable Universities recommended for the accounting of GHG emissions of Italian universities for the year 2016 [32] (where possible, we always used the emission factors recommended by the Italian Network of Sustainable Universities). As the year-to-year variability of this emission factor is very low, we did not update it and we still used the value suggested for the year 2016.

Figure 2 summarizes the entire procedure we use to obtain the carbon footprint for home heating, for producing warm water, and for cooking.

The software Master Energy System allows us estimating the yearly amount of natural gas needed for heating a 120 m^2 single family home or a 80 m^2 flat, starting from the answers to the following questions: Geographical area of residence; Type of dwelling; Period of dwelling construction? Boiler type.

In the ZohoForm tool we start by simplifying the database at the basis of this software obtaining the following data table, which reports the natural gas needed for heating a 100 m^2 average home heated by means of an average efficiency bioler in the areas of Milan, Rome or Naples and in 4 periods of dwelling construction.

Natural Gas (m^3/year) needed for a standard home with standard boiler				
	More than 40 years old buiding	Between 15 and 40 years old buiding	Less than 15 years old buiding	Very recent - quasi zero eneryg building
Milan	2871	1237	715	238
Rome	1828	1167	571	190
Naples	1537	1228	592	197

Then we refine the estimation by means of the following steps:

1 We use a data table with 60 entries combining the heating degree days for the 20 Italian regions and the 3 considered altitudunal levels and we compare these degree days with those of the three cities. This allows us obtaining a better knowledge of the climate of the considered home that we use to correct the estimation

2 We use the answer to the question «How energy efficient is your home?» to correct the estimation in case of energy efficiency interventions (in any)

3 We use the answer to the question «how big is your house?» to adapt the estimation to the surface of the considered home

4 We add the estimation of the yearly amount of natural gas needed for producing warm water and cooking. We get these estimations in (m^3) from the relations: $30 + 40 \cdot n_{fam}$ (for warm water production) and $75 + 12.5 \cdot (n_{fam} - 3)$ (for cooking), where n_{fam} is the number of persons living in the home

5 We share the yearly amount of natural gas between the persons living in the home

6 We use the appropriate emission factor for natural gas to get the individual carbon footprint for home heating, producing warm water and cooking

Figure 2. Procedure for estimating the carbon footprint from home heating, warm water production, and cooking.

2.2. Lighting and Appliances

An accurate quantification of the emissions related to lighting and appliances could, in most cases, be simply based on the electric energy used in a year, as in Italy most families use electric energy only for these applications. Most companies provide this information on the electric energy bill. We did not, however, base our estimation on it because we thought that most people would stop filling in the questionnaire if they were asked to look for a bill. As for natural gas, we therefore tried to obtain an estimation from answers to a few simple questions on issues that are familiar to most people.

We started by presenting a window with the main appliances that people could use, and we asked them to click on those that were used by the compiler (in the ZohoForms tool we did not ask for the refrigerator as we assumed that everyone uses it). In the ZohoForms tool, we then considered the yearly energy needed for a standard version of each of the used appliances (medium size, medium energy efficiency and standard use) and we corrected these values based on how much the different appliances were used by the compiler. In this tool, we did not, therefore, ask for the energy efficiency of the different appliances. However, we provided a reference to the website of the EU Project LABEL 2020 [33], which allowed users to understand the efficiency of the appliances they planned to buy. On the contrary, in the web application, we allowed users to specify if their appliances were younger or older than 5 years and we use this information to obtain an indication on the energy efficiency.

For lighting, in the ZohoForms tool, we first derived the lumen necessary to illuminate the home from its surface and we then asked the user to indicate the average time the home was illuminated on each day. We finally asked the users to indicate how much they had already changed their old low-efficiency lamps to new more efficient ones, and we used this information to obtain the electric energy needed for lighting. On the contrary, in the web application, we asked the user to explicitly indicate how many light bulbs were present in different categories of lighting systems.

We finally summed up the electric energy needed for the appliances and for lighting and we transformed it into $CO_{2\text{-eq}}$ emissions using the emission factor that the Italian Network of Sustainable Universities recommends for the accounting of GHG emissions of Italian universities. This emission factor was regularly updated: the last available value was from 2021 (0.246 kg $CO_{2\text{-eq}}$/kWh). In 2019, when most of the data we discuss in the results section were collected, the value was 0.269 kg $CO_{2\text{-eq}}$/kWh. For the web application, we used the value for 2016 (0.355 kg $CO_{2\text{-eq}}$/kWh).

2.3. Mobility

We estimated the $CO_{2\text{-eq}}$ emissions related to mobility by summing the yearly emissions linked to the different types of motorized travel of owned and public vehicles considered by the user. This required, on the one hand, knowing the emission factors (EFs, kg $CO_{2\text{-eq}}$/km travelled) of these types of motorized travel and, on the other hand, knowing (or estimating) their yearly usage (km travelled).

For the emission factors, we used once more those recommended by the Italian Network of Sustainable Universities [32]. The identification of the correct emission factors for the transport sector presents specific difficulties related to their user dependence, not only on the type of vehicle used but also on the number of people travelling and on the travel context (travel on urban roads, suburban roads, or motorways with regards to road transport; high speed, regional, or urban transport for rail transport; distance travelled by air transport). For road transport, the available sources of EFs are: (i) theoretical data at the time of vehicle registration, (ii) national mean data from the database of the Italian Institute for Environmental Protection and Research (ISPRA), and (iii) data from local public transport agencies (for public transport). The data at the time of vehicle registration are theoretical and they are only useful for vehicle approval; they are much lower than the real values measured on the road as they neglect real driving cycles and the actual conditions of use (e.g., use of headlights, vehicle conditioning). Therefore, this source can hardly be used. Regarding the national database, every year ISPRA publishes an inventory of the emissions from traffic, based on national data of the stock of vehicles and the relative traffic (number, distances travelled, mean fuel consumption, speed for each vehicle type referring to urban roads, suburban roads, or motorways, and other specific parameters) and applying the COPERT methodology used by the European Topic Centre for Air Pollution and Climate Change Mitigation (ETC/ACM) [34]. The ISPRA inventory is annually developed as a verification tool of the international commitments on environmental protection, such as the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Long-range Transboundary Air Pollution (UNECE-LRTAP). Therefore, this database has an official value. Also, for rail transport and aviation, well-established datasets of emission factors are available [32,35,36].

If the vehicles used carry more passengers, it is necessary to assign to each passenger a share of the emissions related to the movement of the vehicle. For cars, a mean occupancy rate of 1.3 is usually used, but there may be significant variations for some types of users and territories [32]. For motorcycles, scooters, and light and heavy commercial vehicles, 1 passenger for each vehicle can be assumed [32]. For buses, the average value depends on the size of the vehicle and the degree of occupation. For example, according to AMAT—the Mobility, Environment and Territory Agency of the Municipality of Milan (one of the most important northern Italian metropolises)—the average value of seats per km on buses in the Milan area, calculated using the capacities of fully laden vehicles, is equal to 50 (average employment rate 60%). The final EF values we used (kg $CO_{2\text{-eq}}$/km travelled per passenger) were therefore based on these mean numbers of people travelling for each vehicle category.

Once the correct emission factor to use for each type of motorized travel was established (see Table 2), we obtained the corresponding estimation of the yearly emissions linked to the user by the product of the travelled distance defined by the user and the relative emission factor for each type of motorized travel.

Table 2. List of all emission factors (EFs) considered in this study. Regarding the EF of different fuel types (i.e., gasoline, diesel, methane, or LPG), the EF for the vehicle (kg $CO_{2\text{-eq}}$/km/passenger) is then obtained considering the estimated fuel consumption of the vehicle and the average number of passengers.

Item	EF	Unit of Measurement
Natural gas consumed for heating own dwelling	1.96	kg $CO_{2\text{-eq}}/m^3$
Electricity (web application)	0.355	kg $CO_{2\text{-eq}}$/kWh
Electricity (ZohoForms)	0.269	kg $CO_{2\text{-eq}}$/kWh
Gasoline car	2.38	kg $CO_{2\text{-eq}}$/L
Diesel car	2.65	kg $CO_{2\text{-eq}}$/L
Methane car	2.75	kg $CO_{2\text{-eq}}$/L
LPG car	1.94	kg $CO_{2\text{-eq}}$/L
Van or SUV	0.184	kg $CO_{2\text{-eq}}$/km/passenger
Minivan and Camper	0.184	kg $CO_{2\text{-eq}}$/km/passenger
Motorcycle and Scooter	0.0720	kg $CO_{2\text{-eq}}$/km/passenger
Train	0.0330	kg $CO_{2\text{-eq}}$/km/passenger
Bus	0.0140	kg $CO_{2\text{-eq}}$/km/passenger
Plane	0.100	kg $CO_{2\text{-eq}}$/km/passenger
Meat and sausage *	19	kg $CO_{2\text{-eq}}$/kg
Fish *	9.0	kg $CO_{2\text{-eq}}$/kg
Fruits and vegetables *	1.6	kg $CO_{2\text{-eq}}$/kg
Dairy products *	7.7	kg $CO_{2\text{-eq}}$/kg
Beef	27.8	kg $CO_{2\text{-eq}}$/kg
Pork and salami	7.6	kg $CO_{2\text{-eq}}$/kg
Chicken and turkey	5.6	kg $CO_{2\text{-eq}}$/kg
Milk	1.4	kg $CO_{2\text{-eq}}$/L
Yogurt	1.8	kg $CO_{2\text{-eq}}$/kg
Cheese	9.9	kg $CO_{2\text{-eq}}$/kg
Eggs	3.4	kg $CO_{2\text{-eq}}$/kg
Fish and shellfish	6.6	kg $CO_{2\text{-eq}}$/kg
Pasta	1.2	kg $CO_{2\text{-eq}}$/kg
Rice	2.0	kg $CO_{2\text{-eq}}$/kg
Seasonal vegetables	0.8	kg $CO_{2\text{-eq}}$/kg
Non-seasonal vegetables	2.6	kg $CO_{2\text{-eq}}$/kg
Seasonal fruit	0.7	kg $CO_{2\text{-eq}}$/kg
Non-seasonal fruit	1.6	kg $CO_{2\text{-eq}}$/kg
Tropical fruit (by air)	11	kg $CO_{2\text{-eq}}$/kg
Legumes	1.1	kg $CO_{2\text{-eq}}$/kg
Sweets	2.2	kg $CO_{2\text{-eq}}$/kg
Dried fruit	1.7	kg $CO_{2\text{-eq}}$/kg
Kitchen oil	3.1	kg $CO_{2\text{-eq}}$/kg
Juice and drinks	0.7	kg $CO_{2\text{-eq}}$/L
Bread	1.4	kg $CO_{2\text{-eq}}$/kg
Beer	0.7	kg $CO_{2\text{-eq}}$/L
Wine	12	kg $CO_{2\text{-eq}}$/L
Coffee	8.4	kg $CO_{2\text{-eq}}$/kg

* food categories present only in the Vaillant web application.

2.4. Food

In Europe, food consumption is one of the main drivers of total GHG emissions [37]. There is, at the same time, the need to fulfil a fundamental human need related to nutrition and, on the other hand, this is posing a critical threat to the environment. However, the impact of each food item is highly variable, even for the same product, depending, for example, on the production and transport system. However, livestock products generally have a considerably larger carbon footprint (CF) than plant-based foods [38], although high

CF values for plant-based foods have been identified for some products that are produced in heated greenhouses, transported by air, or produced in low-yielding systems [39].

Due to the contribution of methane from enteric fermentation in ruminants, beef and lamb meat have high CF values, followed by cheese. Meat from monogastric animals, such as pigs and poultry, is characterized by lower CF values than products from ruminants, but still higher than most foods of vegetal origin due to the large amount of feed needed in livestock production and emissions from manure handling [40].

Another important insight is that direct emissions from livestock production are dominated by pre-farm and on-farm emissions, while post-farm emissions are often considerably smaller [9,40]. For plant-based foods, post-farm stages can make a significant contribution to the total CF, e.g., emissions from transport can be a major contributor to the total CF for fruit and vegetables [41,42].

Estimating the individual carbon footprint due to food considers a very wide range of diet types. Another problem is the uncertainty in the amount of each eaten portion. In addition, people are often not able to correctly define their own diet type. For example, the meat portion is not only steak, but it is included in a wider spectrum of foods, especially in sauces for pasta (e.g., ragù, amatriciana, carbonara). Therefore, in the ZohoForms questionnaire, we asked how many times per week the users ate the foods most representative of the Mediterranean diet and two drinks. For each food, the portion indicatively taken over a day (and not a single meal) was provided.

The emission factor of a food can vary depending on many factors, among which are seasonality, mode of transport, and applied methodology. With regards to seasonality, fruit, vegetables, and fish purchased out of season can be imported from afar or, in the case of vegetables, grown in greenhouses with higher emissions than seasonal products. In addition, food products for which the raw material is imported from afar cause higher emissions than local and seasonal products. Therefore, the distinction between means of transport is also important: a product imported by ship (such as, for example, ginger or wheat) is linked to far lower emissions than a product imported by plane (such as most tropical fruit). In addition, several approaches are available to calculate the emission factor, with different results. The LCA (life cycle assessment) approach, for example, evaluates the impact of the product from the raw materials to the disposal of packaging after consumption.

In this study, the food emission factors (reported in Table 2) were defined following different sources of available data [43–49].

2.5. Municipal Solid Waste

On a global scale, although the waste problem is notable in terms of the amount of increase in object production and consequent accumulation, the waste management sector makes a relatively minor contribution to GHG emissions [50]. However, the waste sector is in a unique position to transition from being a minor source of global emissions to becoming a major saver of emissions due to prevention, reuse, and recycling [51]. Although minor levels of emissions are released through waste treatment and disposal, the prevention and recovery of waste (i.e., as secondary materials or energy) avoids emissions in all other sectors of the economy [51].

Information on waste composition and management data is essential for the calculation of individual carbon footprint because it determines the emissions from biological degradation, incineration and landfills. However, it is much more complex, compared to the previous sectors, to estimate the amount of waste produced in terms of weight through easy questions to ask the user. For this reason, we considered the average waste quantity (tons) for each area of Italy (i.e., northern, central, or southern) from the National Waste Inventory [52] and we used these different contributions to normalize the mean annual $CO_{2\text{-eq}}$ emitted in Italy due to waste by each inhabitant (the total annual value is equal to 14.5 Mt, data relative to the year 2017, from ISPRA [53]). Finally, we corrected this amount based on the level of attention paid by the inhabitants: −25% if the users stated that they were respectful of the rules, or +25% if they declared to not separate waste. The value remained unchanged if separate waste collection was performed partially or sometimes carelessly.

2.6. Additional Emissions

The emissions obtained from the five sections of the questionnaire, obtained by using the emissions factors in Table 2, led to large underestimates of individual carbon footprint, both because they mainly focused only on the direct component of the emissions (we considered a life cycle approach only for emissions related to food) and because these five sections did not include all processes determining the emissions (e.g., production of goods, construction and maintenance of infrastructures, provision of services, and so on).

We therefore considered data from the Italian Greenhouse Inventory published yearly by ISPRA, the National Institute for Environmental Protection and Research [53] and we used these data to estimate the emissions that were not considered by only focusing on the items considered in our questionnaires. These emissions turned out to correspond to about 2700 kg $CO_{2\text{-eq}}$ per person per year [54].

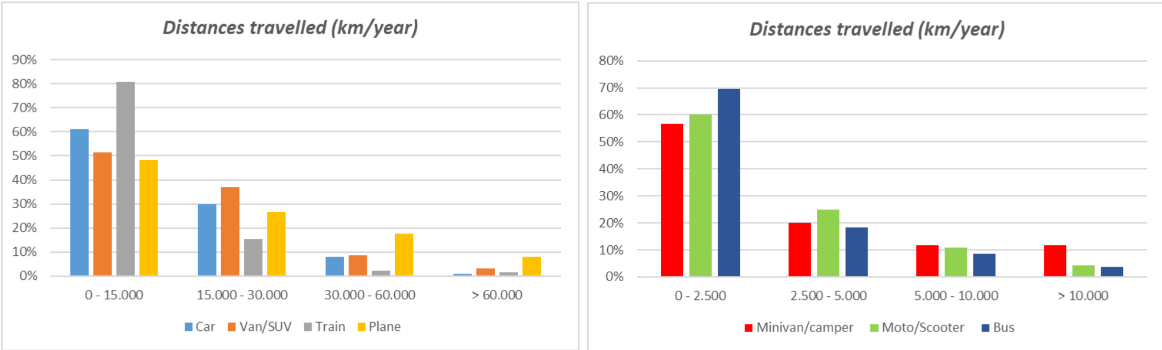
3. Results

The Vaillant web application of our carbon footprint tool was launched on 24 January 2019, when it was presented at a specific event organized at Milan University. This event was a sort of press release that allowed us to give a rather good promotion of the tool, thanks to which the number of users who filled in the questionnaire grew rather rapidly in the first part of 2019. Most of the data we present here were therefore collected in this period. The ZohoForms version was set up in 2022. It has not yet been presented in an event like the one we organized in 2019. We have therefore not yet collected a sufficiently large number of results. In this section, we will therefore mainly focus on the results we collected with the web application.

The formulated questionnaire was filled in by more than 4000 people, but 3260 responses were considered in our analyses (i.e., the ones filled in all sections and without non-sense values), of which 9% of users lived in southern Italy, 11% in central Italy, and 80% in northern Italy. The survey on the type of residential apartment revealed that 63% lived in an "apartment in condominium" and 37% in a "single-family house". A total of 42% of homes were built before 1978, 38% between 1978 and 2005, while only 20% had a more modern construction (after 2005). The number of people living in each apartment was on average 3.0, while the average value of the area of inhabited spaces was 120 m^2. Regarding boilers, 58% of participants used a traditional boiler while 42% used a condensing boiler.

The following focuses on "lighting and appliances." The results showed that almost all people had all three types of light bulbs available in their homes. In particular, the median value was 5 LED bulbs, 4 energy-saving lamps, and 1 halogen bulbs. The average lighting of these was 2.2 h per day. As for household appliances, 49% of people also had an air conditioner in their home, 75% of them had a dishwasher, 74% had a washing machine, and 30% had a dryer. As appliances for "cooking", 88% of the respondents had an electric oven and 15% had an induction cooker. Among the household appliances, we also included the television, investigating which types were most used by people. The results revealed that 46% had a liquid-crystal display TV, 42% had an LED TV, and 12% had a plasma TV. Considering the average daily switching on of the television, we observed that 57% of the compilers kept the TV on for 0 to 3 h a day, 34% for 3 to 6 h, while 10% used it for more than 6 h a day.

We report in Figure 3 the data related to "mobility." We can observe the frequency of using each means of transport and the percentage of annual distances travelled, expressed as a kilometric estimate provided by the users over a year.



(**a**) (**b**)

Figure 3. Average of distances travelled with different means of transport in a year. (**a**) Describes car, van/SUV, train, and plane distances travelled, while (**b**) describes minivan/camper, moto/scooter, and bus distances travelled.

In addition to this information, we also recorded the number of passengers who used intermodal transport choices to move, reporting a diagram that summarizes which combinations of the five means were most popular (more than 90%) among the users (Figure 4).

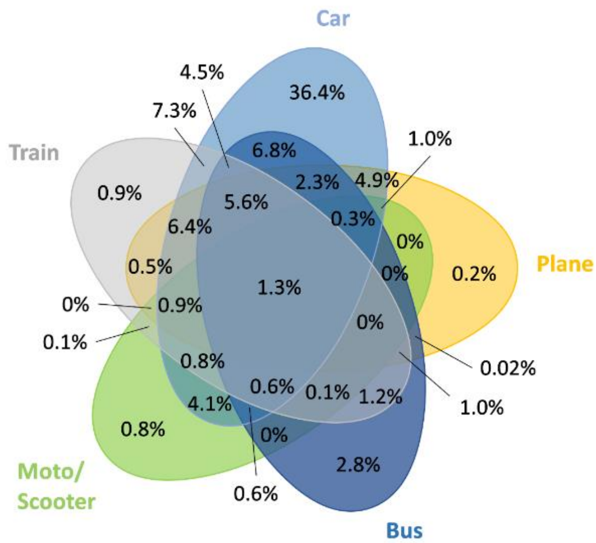


Figure 4. Frequency of intermodal transport.

To better estimate car emissions, users were asked to indicate the type of fuel (43% petrol, 42% diesel, 4% methane, 11% LPG), their fuel consumption in km/L (Figure 5), and the number of passengers they travelled with (on average 2.1).

Moving on to the topic of "food", in the Vaillant web application, we first asked people to indicate what type of diet they followed considering the five most common ones (as proposed by ERS-USDA, the Economic Research Service of U.S. Department of Agriculture): (i) rich in meat, (ii) balanced, (iii) low in meat, (iv) vegetarian, and (v) vegan (Figure 6). Then, we investigated in more depth how often they consumed certain categories of food. We can observe (Table 3) that, regardless of the type of diet, the majority of people consumed plant-based foods every day (84%), while fish was preferred on average once a week.

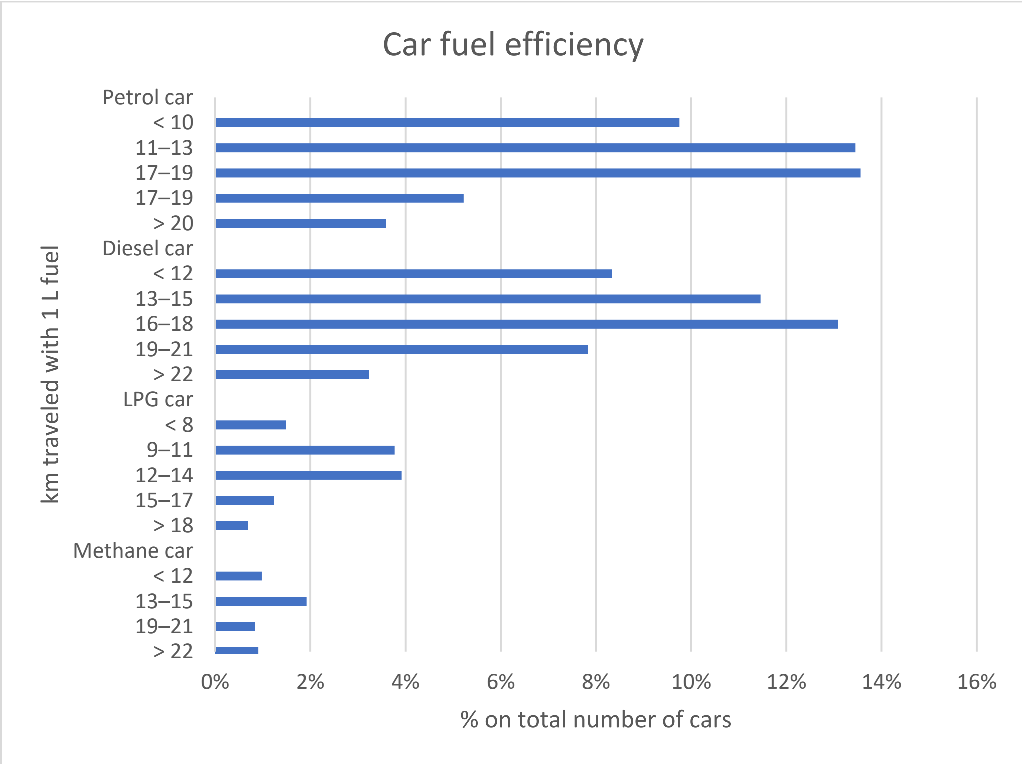


Figure 5. Quantity of km traveled with 1 L of car fuel.

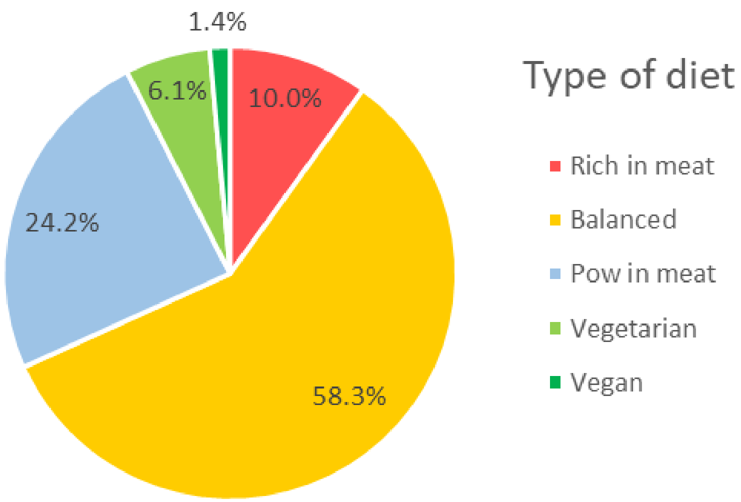


Figure 6. Frequency of each type of diet.

Table 3. Weekly consumption of individual food categories.

	Meat	Fish	Vegetables	Dairy Products
1 time a week	28%	71%	3%	28%
3 times a week	61%	28%	13%	49%
everyday	11%	1%	84%	23%
TOT	100%	100%	100%	100%

Finally, we investigated the method with which separate collection of "municipal solid waste" was carried out. On this front, people seemed to be very informed and aware; in fact, it appeared that only 1% did not do it and 5% did it partially.

To conclude, the total emissions provided by the web application were calculated for each sector analyzed. The graphs below (Figure 7) show the values in terms of kg of $CO_{2\text{-eq}}$. The average annual direct emissions per capita were 5591 kg $CO_{2\text{-eq}}$, with a median value of 4923 kg $CO_{2\text{-eq}}$. The total emissions were then obtained adding 2700 kg $CO_{2\text{-eq}}$ to these values.

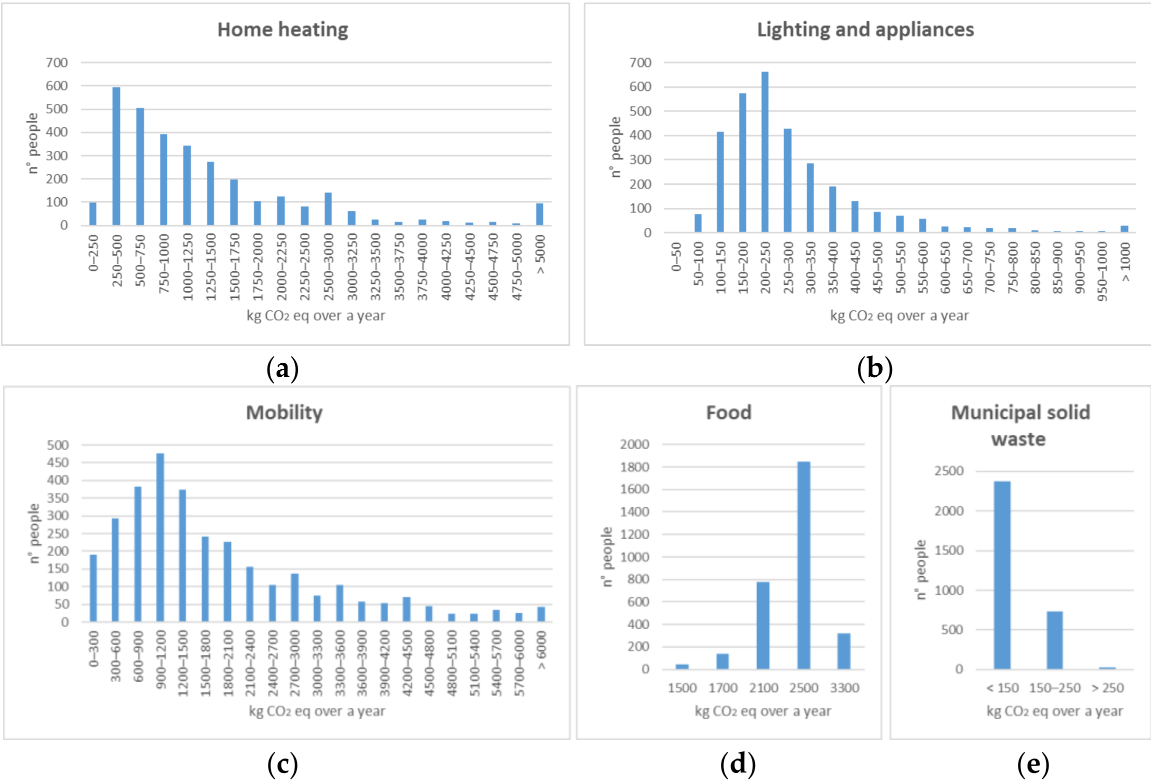


Figure 7. Annual amount of $CO_{2\text{-eq}}$ emitted in the individual sectors analyzed: home eating in (**a**), lighting and appliances in (**b**), mobility in (**c**), food in (**d**), and municipal solid waste in (**e**).

For the ZohoForms version, the average annual direct emissions per capita were 4874 kg $CO_{2\text{-eq}}$. Also, in this case, to obtain the total emissions, it was necessary to add 2700 kg $CO_{2\text{-eq}}$ to these values.

4. Discussion

After presenting the results obtained through our $CO_{2\text{-eq}}$ emissions calculation approach, we proceed with the observations drawn from the data, comparing them with the outcomes of other methods at a national scale. In a subsequent phase, we propose potential developments to improve the system's effectiveness, taking into account the limitations observed during the data analysis.

4.1. Discussion of the Results

We noted that the questionnaire was mainly filled in by individuals living in the northern region, as it was promoted by the University of Milan, located in this geographical area. These data were justified by the affiliation of the entities where the questionnaire was disseminated in this initial experimental phase but also reflects the distribution of the Italian population [50]. Even the average number of members in the same household that emerged from the results (value of 3.0) appeared to reflect the Italian average: this value was 3.1 members in 2018, 2.9 in 2019, and 2.8 in 2020 [55].

Regarding the results obtained on lighting, we realized that it is not easy to identify the type and number of light bulbs present in the home (this is why we decided to not ask for this information in the ZohoForms questionnaire). For this reason, we preferred to report the median of the distribution and not the mean, thus we excluded the most extreme values that were excessively over- or underestimated. Moving to the appliances, the analysis showed that 74% of people had a washing machine. This result may seem surprising, as in 2021, a washing machine was present in almost all Italian households (99.5%) and was among the most energy-intensive appliance in the home [56]. The fairly low percentage found in our results could be because a significant part of the respondents were students, and some of them, living away from home, may not have had a washing machine in the apartment that they rented. In Italy, 27% of university students live off-site, with a growing trend [57]. We also observed that not all people owned an electric oven, suggesting that 12% may have had a gas oven or none at all. This latter assertion could be justified in the same way as for the washing machine.

From the analysis of the results relating to mobility, we observed that the car was the most used means of transport. In general, in European statistics, our nation appears to be among those that make the most extensive use of the car for travelling, as can be seen in Figure 8 [58]. Also, the data obtained on the typology of car fuel reflected the composition of the Italian vehicle fleet [59], according to which the cars in circulation in Italy in 2019 were 46% petrol, 44% diesel, 2.4% methane, and 6.5% LPG.

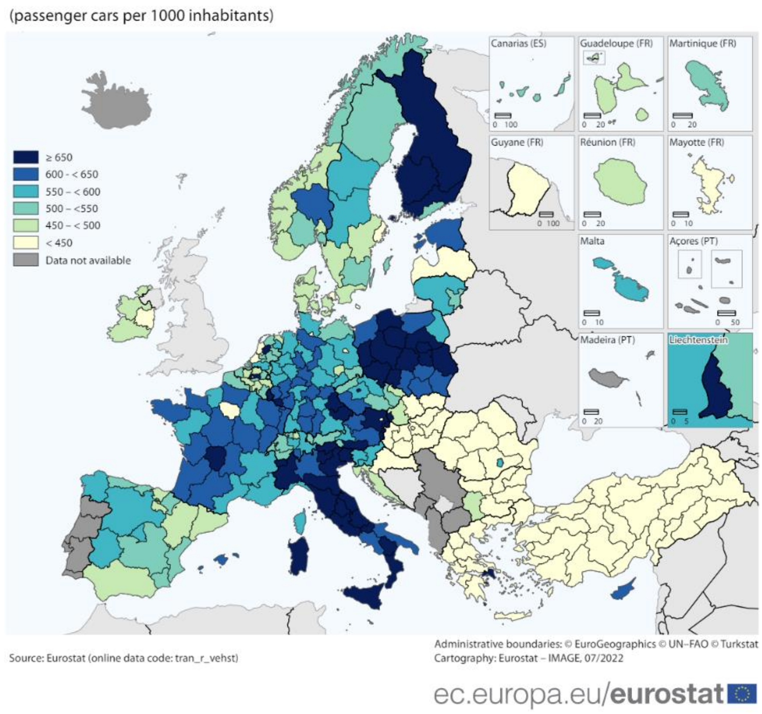


Figure 8. Use of car in European countries.

Treating the data obtained from the "food" section, in the analysis of the results of the Vaillant web application, we noticed a difficulty with the compilers correctly indicating their habits. We initially asked them to indicate their type of diet (rich in meat, balanced, low in meat, vegetarian, vegan), and in a subsequent question, we asked them to express their weekly consumption of the four main food groups. However, we realized that everyone interpreted the definitions of the five types of diet in their way. In the results, we still chose to report the answers given to both questions, but to avoid the problem in the ZohoForms tool, we chose to remove the question on the type of diet and we added more food groups (see Table 2) to provide more clarity and specificity to the information provided.

Every day, we can turn our fork at least three times, choosing what to put on our plate. Among diets, the vegan diet is the one with the least environmental impact [38]. In 2022 in Italy, on average 2.4% of the population claimed to follow a vegan diet [60], a growing value compared to the past (0.6% in 2014). Of these, the majority were young people (the value was 4.8% between 18 and 24 years old), while adults and elderly people appeared to be not so inclined to a vegan diet (value of 0.2%). The data we obtained estimated the number of people with a vegan diet at 1.4% (in 2019), a value in agreement with the Italian percentage.

Regarding "waste", as previously mentioned, the impact in terms of $CO_{2\text{-eq}}$ emissions is minimal compared to that of other sectors. The tool focused on waste separation in the domestic setting, without considering waste differentiation at work or school. In addition, no expressed questions about the recyclability of product packaging during purchase were provided. It could therefore be interesting to expand this section to more specific aspects, maintaining the essentiality of the number of questions.

In the conclusive discussion of sector-specific emissions, a brief comment on emission factors assumes paramount significance. Particularly, those associated with electricity vary more over time; therefore, periodic updating is recommended. In particular, in 2005, $CO_{2\text{-eq}}$ emissions due to electricity production represented 25% of national emissions, while in 2020 the share fell to 19% [61].

In 2019 in Italy, home heating and domestic use of electric energy accounted for 67,342 kt $CO_{2\text{-eq}}$ (equal to about 1100 kg $CO_{2\text{-eq}}$ per person), and the value slightly decreased in 2021 to 65,093 kt $CO_{2\text{-eq}}$ (even if the per capita value remained almost the same since the Italian population was decreased) [53]. The obtained results from our tools reasonably agreed with the national panorama with a mean total emissions of 1700 kg $CO_{2\text{-eq}}$ per person considering both "home heating" and "lighting and appliances." The higher value we obtained was because the questionnaires were filled in mainly by users from northern Italy, which has a colder climate and higher emissions from home heating. Similar to our results, road transport is the most relevant source in the Italian transport sector, accounting for 23% of total national $CO_{2\text{-eq}}$ emissions in 2021, excluding land use, land-use change, and forestry (LULUCF) [53].

A comprehensive Italian inventory for the "food" sector is not available [51]. However, the annual food balance prepared by the Food and Agriculture Organization (FAO) Statistics Division [62] for each country provided a total value of 136705 kt $CO_{2\text{-eq}}$ in 2021 for Italy (equal to about 2300 kg $CO_{2\text{-eq}}$ per person, a value very similar to the one obtained from our web application tool, that is 2432 kg $CO_{2\text{-eq}}$).

The waste sector's share of GHG emissions in the national greenhouse gas total [53] was 4.8% in 2021 (increased by 3.6% from 1990 to 2021), corresponding to a value of 261 kg $CO_{2\text{-eq}}$ per person. The value of emissions for this sector, although it is significantly lower than that obtained in the other sectors, was a little higher than that obtained by us (mean of 156 kg $CO_{2\text{-eq}}$ per person). This was probably due to having considered, as explained before, only domestic waste.

The total individual emissions turned out to be slightly higher than those provided by the Italian GHG emissions inventories. This was probably because the web application tool was mainly used by people in northern Italy who live in a colder climate and have higher emissions for home heating. Another possible cause can be linked to the fact that national averages also take into account people as newborns or very old people with rather low mobility, which consequently cause rather low emissions of GHGs.

4.2. Future Developments

The experience gained during data analysis of the web application allowed us to find some development possibilities, both in the data collection method and communication strategy, to optimize and make the estimation methodology more accurate. Since the developed ZohoForms questionnaire can be modified directly by administrators, these suggestions and others that will arrive can potentially be applied immediately.

For the implementation of the tool, an improvement in data collection, regarding both the impact of heating and electricity, could leave open the possibility of inserting bill data. This seems to be particularly interesting when the tool is used within tutorials performed with students. The precise information from bills would reduce estimation errors and allow a better comparison of variability by geographical area since primary data are available. It would also be interesting to leave open the dual opportunity of entering the values reported on bills and manually adding the values for the use of individual consumer devices. This double information will allow us to compare the data entered with the two methods to carry out an estimate of a parameter that can be used to standardize the data obtained with the two different collection methods, even on other types of questionnaires. Specifically, with regards to heating, it would be interesting to analyze the annual household emissions and also the surface area of the home if bill data were inserted. These data could be more effective than total individual emissions also in highlighting problems related to home insulation or eventual non-sustainable behaviors.

It would also be interesting to investigate how aware people are of their consumption in general; bills can detect this for home heating and electricity, but it would also be interesting to identify more precise parameters for the kilometers traveled by various means of transport and car efficiency. Perhaps more difficult is to find parameters to estimate more precisely the quantity of food consumed in a week.

The opinion of the compiler could be the first and most important point in identifying improvements of the tool at a communicative level. The idea of leaving an open comment to give an opinion on the structure of the questionnaire would allow us to intervene in its efficiency and prevent abandonment in the compilation. At the same time, it could be beneficial to include, alongside emissions-related responses, brief tips on reducing one's emissions. This approach aims to maintain a proactive perspective and avoid discouraging the user.

5. Conclusions and Perspectives

In this study, we present our carbon footprint calculators, which are open-access and user-friendly tools for quantifying individual $CO_{2\text{-eq}}$ emissions. The results obtained during the first phase of the survey agreed with the averages reported in [53], supporting the effectiveness of our method in estimating individual carbon footprint through a few easy questions about one's lifestyle.

Even if these tools were specifically designed for Italy, the ZohoForms version can be easily adapted to other countries, as it can be edited and modified by administrators with rather limited background in computer science. It is therefore rather easy to substitute the Italian emission factors with those of another country. This feature of the ZohoForms tool also allows emission factors to be continually updated when relevant changes occur. This adaptable feature ensures that the results, following the same framework, effectively mirror the lifestyle of individuals contextualized in a specific country and time.

Furthermore, the online questionnaire can be considered an evaluable tool for environmental science education, and it can be linked to earth sciences, physics, chemistry, computer science, and mathematics. In addition, civics is now required at all education levels and as a cross-cutting theme; therefore, increasing individual awareness through our tool can also be considered of didactic utility outside the area of environmental sciences. By entering different data into the online questionnaire, people can experimentally observe that a few actions, even those that are not particularly demanding, can make a difference in individual emissions related to their lifestyle. In fact, our tool does not have the aim of rebuking people if they have a high impact but rather of educating and raising awareness about environmental sustainability.

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