The carbon footprint calculation model for the CAMPAIGNers app

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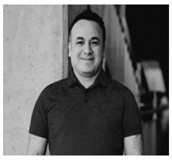

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1. Executive summary

The deliverable 2.1 "The carbon footprint calculation model for the CAMPAIGNers app" represents the first set of results of task 2.1 of the CAMPAIGNers project. The objective of this report is to provide information for a consumption-based carbon footprint calculator for the CAMPAIGNers app. One target is for the app to provide users a rough estimate of their consumption-based carbon footprint. Carbon footprints will be calculated based on a few key questions asked of users and on initial data and assumptions in the app's back-end system.

This deliverable presents consumption categories that have been included in the calculator, as well as limitations and uncertainties. The report also describes main assumptions and initial data selections for the app. The focus has been especially on providing key information for CAMPAIGNers' lighthouse cities and for countries where lighthouse cities are located. It will be possible to update initial data and assumptions later during the project if better or more up-to-date information becomes available.

2. Introduction

One of the features of the CAMPAIGNers app is to provide users specific information about their personal carbon footprint. One target is to ask a few key questions from users in order to provide a rough estimate of their carbon footprint. The idea is not to ask too many questions so as to keep the app interesting and easy to use for as many interested users as possible. Therefore, there will be some uncertainties, and all detailed aspects of users' lifestyles cannot be considered. In the future, it may be possible to obtain user-specific data through the app without asking questions. Another target is to use city- and country-specific values for key parameters of the carbon footprint calculator. The focus is especially on lighthouse cities (LHC) and related countries of the CAMPAIGNers project.

One's carbon footprint is defined as a sum of greenhouse gas (GHG) emissions and removals in a product system based on a life cycle assessment (LCA) using climate change as a single impact category. Different GHGs are expressed as mass in CO_2 equivalents using global warming potential (GWP) factors of GHGs (ISO 14067). Carbon footprint calculations should follow the four phases of LCA defined by the ISO14040 and ISO14044 standards:

1) The goal and scope definition
2) The inventory analysis
3) The impact assessment
4) The interpretation

This report presents the goal and scope definition and the inventory analysis phases for each consumption category of the CAMPAIGNers app's carbon footprint calculations. The impact assessment includes key equations needed for carbon footprint calculations, but the actual impacts assessment phase takes place in the back end of the app.

One's personal carbon footprint can be calculated by various approaches, and the most common ones are production-based and consumption-based. The production-based carbon footprint considers GHGs emitted in a specific geographical region. These emissions can be divided by the population of the region to determine a carbon footprint per person. The consumption-based carbon footprint includes life cycle emissions related to the consumption of a person no matter where these emissions are emitted geographically. (Davis & Caldeira, 2010.) The CAMPAIGNers app uses the consumption-based carbon footprint approach.

When determining an individual's carbon footprint, it is common to divide the carbon footprint into four main categories: mobility, housing, food, and other consumption (e.g., Sitra, 2018; Salo & Nissinen, 2017). In some studies the category of "other consumption" is further divided into manufactured products and services (Lettenmeier et al., 2019; Ivanova et al., 2015). Globally, the average household's GHG emissions are the following: housing (25%), mobility (15%), food (13%), and goods and services (44%) (Ivanova et al., 2015).

The consumption-based carbon footprint has been divided into the following main categories in the CAMPAIGNers app:

- Mobility
- Housing
- Food
- Other consumption

There are also some categories that are not included or cannot be factored into the carbon footprint evaluation. These are, for example, pets, additional apartments or summer cottages (separately), and local waste management systems.

3. Mobility

3.1. Goal and scope

Life cycle–related GHG emissions for different mobility modes can typically be linked to direct emissions from fuel combustion, emissions from fuel or energy production, vehicle manufacturing, vehicle end-of-life processing, and infrastructure building (Chester & Horwath, 2009; EEA, 2018). The majority of GHG emissions from mobility are, however, caused directly by burning fossil fuels (petrol and diesel) in internal combustion engines (EPA, 2021).

A comprehensive analysis of mobility-related carbon footprints would require inclusion of all relevant life cycle stages and collection of multiple user-specific initial parameters. However, because a user-specific carbon footprint calculator only sets a starting point for #Lifestylechallenges of the CAMPAIGNers app, the aim is to keep it rather simple and user-friendly. Therefore, it has been decided to concentrate on direct GHG emissions and on emissions from fuel and energy production. These life cycle stages typically represent over 80% of total life cycle GHG emissions related to mobility. Vehicle and infrastructure manufacturing as well as end-of-life processing have typically less importance in total GHG emissions (Chester & Horwath, 2009). It is also more challenging to obtain specific data related to these life cycle stages for vehicle in various geographical location. There has been discussion especially related to the higher manufacturing emissions of electric cars in comparison to those of internal combustion engine cars due to battery manufacturing (EEA, 2018). However, it has also been shown that emissions related to battery manufacturing have been declining (Emilsson & Dahllöf, 2019).

The goal of the CAMPAIGNers app in the mobility category is to calculate the annual carbon footprint (GHG emissions as $kgCO_2eq$) for app users' annual personal mobility, including direct GHG emissions and emissions from fuel and energy production for selected mobility modes (Figure 3.1).

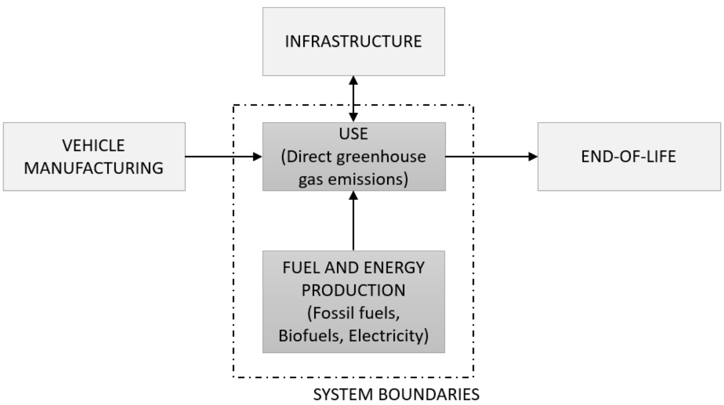

Figure 3.1: System boundaries for life cycle GHG emissions related to users' mobility

There are multiple mobility modes available in different regions, and the inclusion of all possible options would make the app complex for users. Therefore, only the most common mobility modes have been included (Table 3.1). LHCs have raised mobility emission reductions as one of their priorities and, therefore, the mobility-related category has been developed to be a little more detailed than other consumption categories. Walking and cycling have been included in the app despite the fact that they do not produce GHG emissions from life cycle stages within the selected scope.

Table 3.1: Mobility modes for the CAMPAIGNers app (LHC=lighthouse city).

Mobility mode	Fuel options
Passenger car	- Petrol, diesel, non-plug-in hybrid - Biofuel usage in high blends/shares - Battery electric - Plug-in hybrid
Bus	- Diesel - Mix of diesel, biofuels, natural gas, and electricity (LHCs)
Train, tram, and metro	- Electric - Mix of diesel and electricity (LHCs)
Motorcycle, moped, and microcar	- Petrol, diesel
Electric bike/scooter	- Electricity
Cycling	
Walking (also skateboarding, skating, skiing, etc.)	
Aviation	- Kerosene
Ferry	- Fossil fuels

3.2. Inventory analysis

This chapter presents basic assumptions and data for the mobility carbon footprint calculations. The chapter has been divided into two main parts: 1) direct emissions from fuel usage (burning) and 2) emissions from fuel and energy production.

From a user's perspective, mobility emissions are typically linked to mobility distances with different mobility modes. A key question for users is their annual mobility by different mobility modes in kilometres. In the future, it could be possible to obtain measured data related to users' mobility distances by, for example, using GPS in the app. At first, users are asked about their weekly mobility distances by mobility modes within the scope of the app. In addition, aviation is based on hours annually flown because it has been assumed that it is easier to assess aviation as hours instead of kilometres.

3.2.1 Direct GHG emissions from vehicle-use phase

Direct GHG emissions from mobility are typically linked to the burning of fossil fuels in vehicle engines (or turbines). The following chapters explain basic assumptions and initial data related to direct emissions for different mobility modes.

Passenger car emissions depend on several factors such as a car model and driving style. It is typically easy for users to get information related to average direct CO_2 emissions for various car models (gCO_2/km). Therefore, users can set a car-specific emissions factor for direct CO_2 emissions according to information about their own car model. If a user does not provide this information, the default value for passenger car direct emissions is 150 gCO_2/km. This assumption is based on the fact that cars in EU are on average 11.5 years old (Acea, 2021) and roughly corresponds to emissions of new cars in 2008–2009 (EEA, 2021a).

The calculation of direct CO_2 emissions is complicated by the fact there are also typically non-fossil fuels (bio or renewable) in fuel blends. A share of these biocomponents in fuels in the EU and globally varies between countries but can be assumed to be on average approximately 10% (ePURE, 2020). Emissions from biocomponents are regarded as biogenic and will be deducted from total direct emissions (Directive 2018/2001/EC). There are also passenger cars that are mainly operated using non-fossil fuels. These cars can operate with, for example, biogas, ethanol, or renewable diesel in high blends. It has been assumed that these cars have only biogenic direct emissions.

Electric cars do not have direct GHG emissions from driving. Plug-in hybrid cars can operate either on fuel or electricity. Users have a key role related to a share of electricity in total driving, and according to various research papers, this may vary at high scale. However, it seems that typical shares are 50% for electricity and 50% for fuel. (Autoalan tiedotuskeskus, 2020.) The direct emissions of hybrid cars are, therefore, assumed to be 50% of the direct emissions of typical passenger cars.

Car-related emissions should be allocated depending on the number of people in a car (driver and passengers) to get user-specific emissions. Therefore, each user is asked to estimate the average number of people who ride in a car they use. Default passenger car occupancy in Europe is approximately 1.4 people (Eurostat, 2021b).

Buses can typically operate with diesel, biofuels, or electricity. Passenger-specific emissions of buses are also dependent on passenger occupancy rates. A default assumption is that direct emissions from EURO 5 diesel buses (based on a mixture of urban arterial and steer driving with a 50% passenger occupancy rate) is approximately 38 gCO_2eq/p-km (including biogenic CO_2 from biocomponents, which is deducted in calculations) (Technical Research Centre of Finland, 2017). Emissions for long-distance buses may differ slightly from the default value used in the app. However, the bus category selected for the app can also be used to estimate emissions related to long-distance buses. LHCs have the opportunity to set a city-specific emissions factor or shares of energy sources for their buses; these are presented in Appendix I.

Trains, trams, and **metros** typically operate using electricity, especially in cities. In Europe, 80% of passenger rail transport activity operates nowadays by electricity (IEA, 2019). Therefore, these means of transport are assumed to have no direct GHG emissions. LHCs have an opportunity to provide city-specific information on the energy sources (diesel/electricity) of local trains (Appendix I). For diesel trains, direct emissions have been calculated based on average train fuel consumption and the assumption that 94 gCO_2eq/MJ is released from fossil fuel use (Directive 2018/2001 EC).

Motorcycle, moped, and microcar emissions are calculated according to the assumption that they use fossil petrol or diesel as fuel. The estimate is that GHG emissions are approximately 109 gCO_2/km for motorcycles, 68 gCO_2/km for mopeds, and 127 gCO_2/km for microcars. The average of these numbers is 101 gCO_2/km and will be used in the app for mobility within this category. These emissions include biogenic carbon emissions from the fuel's biocomponent. (Giechaskiel, 2020; Technical Research Centre of Finland, 2017.)

Electric bikes and **electric scooters** have been assumed to have no direct emissions.

Aviation is mainly operated by fossil kerosene. Emissions are dependent on plane type, passenger numbers, and flight length. For shorter distances, emissions per passenger-km are typically higher because takeoff consumes a lot of fuel. For shorter flights, takeoff emissions are allocated for fewer kilometres. In addition, planes for longer flights are typically bigger and more energy-efficient per passenger. According to Graver et al. (2020), regional flights emit approximately 160 gCO_2 per passenger-km, medium-haul flight emit 110 gCO_2 per passenger-km, and long-haul flights emit 90 gCO_2 per passenger-km. Only one category of flights has been included in the app. Its GHG emissions are calculated based on the emissions of a medium-haul flight and on the assumption that average flight speed is 800 km/h. Based on these assumptions, emissions per flight time are 88 $kgCO_2/h$.

Ferries are an option for passenger mobility in some of the LHCs. Therefore, ferry trips have been included in the calculator. Total emissions for ferries have been assumed to be 112 gCO_2eq/pkm (pkm=passenger kilometres) (UK Government, 2021).

3.2.2 Fuel and energy production–related emissions

Fuel and energy production related emissions are typically linked to fossil and non-fossil fuel production as well as to electricity production.

Passenger cars

Emissions from fossil petrol and diesel production can be linked to, for example, oil pumping, distribution, and distillation processes. According to the European Commission (2015), GHG emissions from fossil fuels sold in EU areas are approximately 20 gCO_2eq/MJ for petrol and diesel. There are also approximately 10% of biofuels in the EU fuel blend (ePURE, 2020). The EU is regulating maximum carbon footprints for biofuel production (Directive 2018/2001/EC). According to directive 2009/2018/EC, there is high variation in biofuel production related to GHG emissions. In the CAMPAIGNers app, a basic assumption is that biofuels are mainly produced using waste feedstock and that 20 gCO_2eq/MJ is a rough estimate for their production-related emissions.

Fuel consumption is linked to direct CO_2 emissions from fuel burning. Therefore, in the app, emissions related to fuel production are calculated based on the direct emissions of a passenger car. Based on data provided by the Technical Research Centre of Finland for direct vehicle emissions and fuel consumption, it can be calculated that emissions related to fossil diesel and petrol production are roughly 29% of total direct emissions (including biogenic emissions). This assumption has been used in the CAMPAIGNers app for petrol, diesel, and non-plug-in hybrid passenger cars.

As mentioned earlier, some passenger cars can use biofuels such as ethanol, biogas, or renewable diesel in high blends. The basic assumption for fuel consumption is 2.2 MJ/km for average-aged passenger cars in the EU (Acea, 2021; Technical Research Centre of Finland, 2017). Therefore, using biofuels in high shares leads to 44 gCO_2eq/km from fuel production.

Electric car electricity consumption varies from 10 to over 30 kWh/100km, but for the CAMPAIGNers app, it is assumed to be on average 20 kWh/100km (Weiss et al., 2020). For emissions related to electricity production, a local grid mix is used if applicable. Emissions related to electricity production are applicable both for plug-in hybrids and electric cars.

Buses

Diesel production for buses has been modelled along similarly lines to diesel production for passenger cars. The basic assumption is that GHG emissions related to fuel production are 29% of total direct GHG emissions.

Trains, trams, and metros

According to the IEA (2019), trains in Europe consume approximately 340 kJ/pkm of energy. It is assumed that trains are mainly powered by electricity. Emissions related to the production of consumed electricity are calculated using country-specific electricity grid mix emission factors. It should be noted that some rail companies may purchase their electricity only from renewable sources, but this has not been considered in the app.

Motorcycles, mopeds, and microcars

Petrol production for motorbikes has been modelled along similar lines to diesel production for passenger cars. The basic assumption is that GHG emissions related to fuel production are 29% of total direct GHG emissions.

Electric bikes and **electric scooters**

The electricity consumption of e-bikes and e-scooters varies, but for the app, the average values presented by Weiss et al. (2020) have been chosen. The approximate electricity consumption of e-bikes is 0.6 kWh/100km and of e-scooters 1.5 kWh/100km. In general, the assumption of 1 kWh/100 km has been used in the app for this mobility category. In some cases, e-scooters are transported within a city by a van for charging, which may cause additional emissions. However, this possibility is not considered in the CAMPAIGNers app.

Aviation

Kerosene production for planes has been modelled along similar lines to diesel production for passenger cars. The basic assumption is that GHG emissions related to fuel production are 29% of direct GHG emissions.

3.3. Impact assessment

In the impact assessment phase, carbon dioxide equivalent (CO_2eq) emissions are calculated for users' mobility. This is done first by calculating emissions per passenger kilometres for each mobility mode. Then users' mobility (in kms) is multiplied by the emission factors specific to the mobility mode. The following equations show the calculation logic for some of the example mobility modes.

Petrol, diesel, and non-plug-in hybrid passenger car emissions have been calculated by combining direct fossil emissions and emissions related to fuel production:

$$E_{car} = E_{dir} \cdot \frac{100-b}{100} + E_{dir} \cdot \frac{f}{100} \qquad [1]$$

, where E_{car} is emissions for passenger cars (gCO_2eq/km)
E_{dir} is direct emissions from a car (gCO_2eq/km)
b is the share of biofuels in the fuel blend (%)
f is emissions related to fuel production in relation to direct emissions (%)

User-specific emissions from car usage are calculated by the following equation:

$$CF_{car} = \frac{E_{car} \cdot D}{p} \cdot 52\,weeks \qquad [2]$$

, where CF is emissions for passenger car usage ($kgCO_2eq/a$)
D is users' weekly passenger car mobility (km/week)
p is the average amount of passengers in a car (persons)

By using basic assumptions for each factor, the following emissions can be calculated for a passenger car (equation 1):

$$E_{car} = \frac{150gCO_2eq}{km} \cdot \frac{100-10}{100} + \frac{150gCO_2eq}{km} \cdot \frac{29}{100} = 178.5\ gCO_2eq/km$$

User-specific annual emissions with 50 km of driving and an average of 1.4 persons can be calculated as follows (equation 2):

$$CF_{car} = \frac{\frac{178.5gCO_2eq}{km} * 50km}{1,4} \cdot \frac{1kg}{1000g} \cdot 52\ weeks = 331.5\ kgCO_2eq/a$$

Another example is related to the use of trains. The following equation shows emissions from train usage per kilometre:

$$E_{train} = e_{el-pkm} \cdot CF_{el} \qquad [3]$$

, where e_{el-pkm} is the average train electricity consumption per passenger km (kWh/pkm)
CF_{el} is emissions from electricity production (gCO_2eq/kWh)

User-specific emissions from train usage can be calculated by the following equation:

$$CF_{train} = E_{train} \cdot D \cdot 52\ weeks \qquad [4]$$

, where CF is emissions for train usage ($kgCO_2eq/a$)
D is users' weekly train travelling (km/week)

By using basic assumptions for each factor, the following emissions can be calculated for a passenger car (equation 3):

$$E_{train} = 0.09\frac{kWh}{pkm} \cdot 255\frac{gCO_2eq}{kWh} = 24.1gCO_2eq/pkm$$

User-specific annual emissions with 50 km of driving and an average of 1.4 persons can be calculated as follows (equation 4):

$$CF_{train} = 24.1\frac{gCO_2eq}{pkm} \cdot 50km \cdot \frac{1kg}{1000g} \cdot 52\ weeks = 62.6\ kgCO_2/a$$

.

4. Housing

4.1. Goal and scope

Globally, buildings and construction account for 29% of energy-related GHG emissions which, in turn, account for approximately two-thirds of all global GHG emissions (Dean et al., 2016). The energy consumption of buildings account for approximately 75–80% of the life cycle GHG emissions whereas the rest are embodied emissions deriving from, for example, construction, maintenance, and the end-of-life stages (Röck et al., 2020).

Similarly, to estimate users' mobility-related carbon footprint, a collection of multiple user-specific parameters would be needed for a comprehensive analysis of users' housing-related carbon footprint. As the aim of the CAMPAIGNers app is to be rather simple for the users, it was decided not to ask too many specific questions. For example, the age and type of the users' housing are not asked, even though these factors affect the space heating needed. In addition to emissions related to heating and electricity production, the embodied emissions from life stages are included. The infrastructure needed for energy production is not considered.

The goal of the CAMPAIGNers app in the housing category is to calculate the annual carbon footprint (GHG emissions as kgCO_2eq) for app users' housing, including direct and indirect GHG emissions from heating and electricity production and embodied emissions from construction, maintenance, and the end-of-life stages.

The following heating options are available in the calculator:

- Electricity
- District heating
- Natural gas
- Heat pumps (ground source, air-to-air, air-to-water)
- Wood chips and biomass
- Heating oil
- Coal
- Renewables (e.g., geothermal, solar)

4.2. Inventory analysis

This chapter presents basic assumptions and data for the housing carbon footprint calculations. In this chapter, direct emissions from fuel usage (e.g., burning heating oil) and emissions from energy production (e.g., district heating) are not separated. The majority (75–80%) of housing-related CO_2eq emissions are derived from energy usage, especially when "standard" housing is discussed. In newer, that is, more energy-efficient housing, the percentage of embodied emissions is higher while the energy consumption is lower (Röck et al., 2020).

Users of the app are first asked how many persons are living in their household and the area of the apartment/house. If they know their household's annual electricity and heating consumption, they can fill out this information. If users have, for example, a summer house, they can add the total energy consumption of their housing. Users are asked to input their net consumption, so if they have, for example, solar panels, they can take that into account. If the user does not know the energy needed for space heating, the value is estimated based on national or other geographical averages. The values are presented in table 4.1. In reality, there is a lot of variation in space heating needs of households due to, for example, the location, and type of the age of the housing.

Table 4.1: Space heating values for participating countries.

Country	Austria	Azerbaijan	Canada	Finland	France	Greece	Ireland
Space heating [kWh/m²]	152 [a]	135[e]	133 [b]	216 [a]	131 [a]	105 [a]	97 [a]
Country	**Italy**	**Lithuania**	**Peru**	**South Africa**	**Sweden**	**Turkey**	**EU**
Space heating [kWh/m²]	99 [a]	125 [a, c]	6[e]	–[f]	124 [a]	85 [d]	58 [e]

[a] EEA, 2015 (climate-corrected values)

[b] Natural Resources Canada

[c] The EU's average

[d] GIZ, 2018. Average of four climate zones and single- and multifamily houses

[e] IEA, 2021c. 2020 average for Central and South America (Peru) and for Eurasia (Azerbaijan)

[f] Heating is only rarely used in South Africa.

Similarly, in the event that users do not know the real electricity consumption of their household, the value is estimated as the annual kWh consumption per person, including electricity used for lighting, appliances, and cooking. The values used are presented in table 4.2. It is acknowledged that, for example, the type of the housing and living habits cause variation in the electricity consumption, but for simplicity's sake, the users are not asked these questions in this phase. In Peru, the annual average household-related energy consumption, excluding operation of private vehicles, was 853 kWh/capita (including all ages) during 2015 (Cardenas-Mamani et al., 2022). In the app, it is assumed that 30% of the energy consumption is used for water heating. Possible heating and cooling are included in the energy consumption which might lead to double counting in some users' cases. However, as stated by Cardenas-Mamani et al. (2022), heating and cooling are rare in Peruvian households due to mild climate. In addition to electricity, liquified petroleum gases and natural gas are used in Peruvian households. In the calculations, it has been assumed that only electricity is used. As Peru's emission factor for electricity is 285 gCO_2eq/kWh (table 4.6), and emission factors for LPG and natural gas are 281 gCO_2eq/kWh and 240 gCO_2eq/kWh (Koffi et al. 2017a), the assumptions only make little difference in carbon footprint. For Azerbaijan and Turkey, average value of the EU is used, as no specific data on household energy consumption was found.

In the average value of electricity usage, the possible use of air-conditioning is not included. Thus, if users cannot provide actual information regarding electricity consumption, they are also asked how many hours they use air-conditioning per week. There are differences in energy consumption of air conditioners, but for the app, it is assumed that an average unit uses 3 kWh/hour of electricity (Brown, 2021). Users are also asked how many air-conditioning units are in use. Similarly, they are asked about the use of portable electric heaters and the number of units in use. There are differences also in the energy consumption of electric heaters. In the app, an estimate of 1 kWh/hour is used (Hughes, 2022). It has also been assumed that cooling and electric heaters are included in total electricity consumption if the users define them themselves. It is acknowledged that, for cooking, other fuels apart from electricity are used as well. For simplicity's sake, it has been assumed that cooking is done using electricity. In the EU, only 6.1% of household energy consumption is used for cooking (Eurostat, 2021d).

Table 4.2: Used values for annual electricity consumption per person, including lighting, appliances, and cooking.

Country	Austria	Azerbaijan	Canada	Finland	France	Greece	Ireland
Electricity consumption [kWh/person]	1304 [a, b]	1287 [a, b, d]	2148 [e]	1767 [a, b]	1858 [a, b]	1271 [a, b]	1537 [a, b]
Country	**Italy**	**Lithuania**	**Peru**	**South Africa**	**Sweden**	**Turkey**	
Electricity consumption [kWh/person]	1310 [a, b]	1456 [a, b]	744 [f, g]	900 [c]	2090 [a, b]	1287 [a, b,]	

[a] Eurostat, 2022. Data from 2019
[b] Eurostat, 2021c. People aged 12 years or older taken into account
[c] Hughes & Larmour, 2021
[d] Average value for EU (EEA 20021b)
[e] Pareth et al., 2012. 2.8 persons assumed per household (2 adults and 0.8 school-aged children)
[f] Cardenas-Mamani et al., 2022
[g] Statista, 2022. People aged 15 or older taken into account

GHG emissions for heating options, including natural gas, wood chips (biomass), heating oil, and coal, consider life cycle emissions and include different GHGs. The factors include emissions from combustion and from the supply chain: exploitation, transport, and processing (Bertoldi et al., 2010).

The emission factors for different heating options are listed in table 4.3.

Table 4.3: Emission factors for heating options.

Heating/fuel	Natural gas	Wood chips	Heating oil	Coal	Renewables (e.g., geothermal, solar)
Emission factor [gCO_2eq/kWh]	240[b]	17[b]	306[b]	370[b]	0[c]

[b] Koffi et al., 2017a

[c] Does not include emissions from the manufacturing of devices or from possible electricity consumption (e.g., for pumping)

Emissions from district heating are area-specific due to different shares of fuels being used for producing heat. Thus, city-specific emission factors were obtained from LHCs. Some country-specific emission factors have been calculated based on various data sources. A default value for district heating has been calculated based on shares of different fuels in district heating production in Europe in 2019, according to information from the IEA (2020) and on the carbon intensities of fuels (table 4.3). As a result, the default carbon intensity for district heat production is 175 gCO_2eq/kWh. Emission factors for district heating for LHCs are listed in table 4.4.

Table 4.4: Emissions factors for district heating for countries and cities where district heating is utilised.

Country	Austria	Azerbaijan	Canada	Finland	France	Greece	Ireland
Emission factor [gCO_2eq/ kWh]	Country: 90 [a] Freistadt: 28 Linz: 241	Country: 198 [b] Baku: X	Country: 198 [b] Trois-Rivières: n/a	Country: 148 Lahti: 57	Country: 115 [a] LDH Grenoble: X	Country: LDH Skopelos: n/a	Country: LDH Dublin: n/a
Country	**Italy**	**Lithuania**	**Peru**	**South Africa**	**Sweden**	**Turkey**	
Emission factor [gCO_2eq/ kWh]	Country: 148 [a] LDH Milan: X	Country: 112 [b] Vilnius: 189	Country: 198 [b] La Libertad (Trujillo): n/a	n/a	Country: 230 [a] Malmö: X	Country: 198 [b] Izmir: 0	

n/a: not applicable in the city or country

DH in Izmir is based on geothermal energy and, therefore, emissions have been assumed to be 0.

DH in Freistadt is 95% biofuels and 5% natural gas.

BH in Vilnius is 77% natural gas and 23 % biofuels.

[a] Wedistrict, 2020. LDH=low share of district heating at a country level.

[b] Werner, 2017. The EU average has been used for Lithuania and the world average for Azerbaijan, Canada, Peru, and Turkey.

Emissions from using ground source heat pumps, air-to-air heat pumps, or water-to-air heat pumps depend on the emission factor of used electricity. The Seasonal Performance Factor (SPF) describes the average annual energy performance. For example, if a pump's SPF is 4, the pump uses 1 kWh of electricity to produce 4 kWh of heating energy. In the CAMPAIGNers app, a SPF of 3.5 is used for all three heat pump technologies. It is possible to even reach an SPF of 7 with currently available technologies in milder climates. (IEA, 2021b; Laitinen et al. 2014). However, some of the CAMPAIGNers app users are from cold climates and, furthermore, it cannot be assumed that they use the most current technology.

Values for heating energy consumption are based on average space heating values. If the users define the heating energy consumption themselves, they are asked whether water heating is included. If the user answers no or a default value for space heating energy consumption is used, an average value for GHG emissions from water heating [kgCO_2eq/person] is used. The values are presented in table 4.5. For EU values, the emissions are calculated based on annual energy use for water heating (Eurostat, 2022) in 2019, populations (Eurostat, 2021c), the shares of different fuels (Eurostat, 2021d), and emission factors presented in tables 4.3, 4.4, and 4.6. The value used for South Africa is calculated based on Hughes & Larmour (2021).

Table 4.5: Average annual emissions per person caused by water heating.

Country	Austria	Azerbaijan	Canada	Finland	France	Greece	Ireland
Emissions [kgCO_2eq /person]	183 [a, b] Freistadt: 174 Linz: 206	185 [a, b, e]	185 [a, b, e]	274 [a, b] Lahti: 169	133 [a, b]	190 [a, b]	440 [a, b]
Country	**Italy**	**Lithuania**	**Peru**	**South Africa**	**Sweden**	**Turkey**	
Emissions [kgCO_2eq /person]	191 [a, b]	68 [a, b] Vilnius: 92	91 [f, g]	1010 [c] 449 [d]	197 [a, b]	185 [a, b, e]	

[a] Eurostat, 2022. Data from 2019
[b] Eurostat, 2021c. People aged 12 years or older taken into account
[c] Hughes & Larmour, 2021. Value for hot water geyser
[d] Hughes & Larmour, 2021. Value for solar water heater (+hot water geyser)
[e] Average value for EU
[f] Cardenas-Mamani et al., 2022
[g] Statista, 2022. People aged 15 or older taken into account

Emission factors for electricity are country-specific. The values for 137 countries are based on Lo Vullo et al.'s (2020) dataset. These values are based on total national GHG emissions from electricity production from all input energy carriers and the total final energy consumption. In other words, total GHG emissions from national electricity production is divided by total national electricity consumption. The GWPs used are taken from the IPCC Fourth Assessment report. Combustion emissions from biomass and biofuels are included in the emissions if the fuel does not meet carbon neutrality criteria, that is, total compensation of CO_2. (Koffi et al., 2017b.) However, emission factors for electricity are needed as emissions from production per amount of electricity produced, not per electricity consumed, because the amount of electricity produced in a country may not be the same as the electricity consumed. The following equation was used for calculating emissions from electricity production based on Lo Vullo et al.'s (2020) values (equation 5). Values for electricity consumption are from the IEA (2021a). The values for total electricity production $e_{el\ prod}$ were calculated using the IEA (2021a) country-specific values by subtracting national electricity consumption from net import.

$$CF_{prod} = CF_{con} * e_{el\ con}/e_{el\ prod} \qquad [5]$$

, where CF_{prod} is the emission factor for emissions from electricity production per unit of electricity produced [gCO_2eq/kWh]

CF_{con} is the emission factor for emissions from electricity production per unit of electricity consumed [gCO_2eq/kWh]

$e_{el\ con}$ is the total electricity consumption [kWh]

$e_{el\ prod}$ is the total electricity production [kWh]

Emission factors for countries with LHCs are listed in table 4.6 and are the mean values of three years (2013–2015 or 2016–2018). The emission factors for electricity are also used for the mobility category for vehicles using electricity. Users of the app have an opportunity to choose if they have a "green" or a "zero emission" electricity contract.

Table 4.6: Emission factors for electricity used in housing and mobility.

Country	Austria	Azerbaijan	Canada	Finland	France	Greece	Ireland
Emission factor [gCO_2eq/kWh]	165[a, c, d]	640[a, c, d]	137[a, f]	124[a, c, d]	70[a, c, d]	623[a, c, d]	434[a, c, d]
Country	**Italy**	**Lithuania**	**Peru**	**South Africa**	**Sweden**	**Turkey**	
Emission factor [gCO_2eq/kWh]	361[a, c, d]	123[a, c, d]	285[b, c, d]	901[e]	13[a, c, d]	573[b, c, d]	

[a]2016–2018
[b]2013–2015
[c]Lo Vullo et al., 2020
[d]IEA, 2021a
[e]Smith et al., 2021. Emission factor for 2020
[f] Environment and Climate Change Canada, 2021

In addition to emissions related to energy, the embodied emissions of buildings are considered. The value of 6.7 $kgCO_2e/m^2$ per year (Röck et al., 2020) is used in the app's calculation. In more advanced residential buildings, the embodied emissions are on average higher (Röck et al., 2020). However, as the age of the housing is not asked from users for simplicity's sake, the same value is used for all. It is also acknowledged that there is a lot of variation between building materials of buildings in different countries.

4.3. Impact assessment

In the impact assessment phase, carbon dioxide equivalent (CO_2eq) emissions are calculated for users' housing. This is done by calculating GHG emissions from electricity (lighting, appliances, and cooking), space heating, air conditioners, electric heaters, water heating, and embodied emissions, and then summing them up.

In the case of electricity and heating, consumption (in kWhs) is multiplied with the production-related specific emission factors. For example, in cases when users don't know their energy consumption, emissions from heating are calculated as follows:

$$CF_{heating} = \frac{A * H * E_{heating}}{p} \qquad [6]$$

, where $CF_{heating}$ is the carbon footprint of heating ($kgCO_2eq/a$)
A is the area of the house/apartment (m^2)
H is the national average for space heating (kWh/m^2)
$E_{heating}$ is the national/global emission factor for the selected heating option
p is the number of people in the household (12 years or older)

For example, the carbon footprint of space heating for a Finn living in a house of 110 m^2, using district heating, with 3 persons over 11 years old, is calculated as follows (equation 6):

$$CF_{heating} = \frac{110\, m^2 \; * \; 216\, kWh/m^2 \; * \; 0{,}148\, kgCO_2eq/kWh}{3} = 1172\, kgCO2eq$$

If users do not know their real electricity consumption, GHG emissions from air conditioners per user are calculated as follows:

$$CF_{AC} = \frac{(3\frac{kWh}{h} * D * n * E_{electricity} * 52\, weeks)}{p} \qquad [7]$$

, where CF_{AC} is emissions for usage of air- conditioning ($kgCO_2eq/a$)
D is user's weekly usage of air-conditioning per AC unit (h/week)
n is number of AC units
$E_{electricity}$ is the national emission factor for electricity ($kgCO_2eq/kWh$)
p is the number of people in the household (12 years or older)

For example, a Turkish user uses two air conditioners for 10 hours a week on average in a 4-person household. The carbon footprint of air conditioning follows (equation 7). The carbon footprint for portable electric heaters are calculated similarly.

$$CF_{AC} = \frac{3\, kWh/h \; * 10\, h/week \; * \; 2 * \; 0{,}573 \; kgCO2eq/kWh * 52\, weeks}{4} = 447\, kgCO2eq$$

5. Food

5.1. Goal and scope

Globally, GHG emissions related to food systems represented 34% of total GHG emissions in 2015. The majority of these emissions, 71%, were from agriculture and associated land-use and land-use change activities. The remaining emissions were from supply chain activities such as transport, consumption, packaging, industrial processes, and fuel production. (Crippa et al., 2021.) Approximately 57% of nutrition-related GHG emissions are from animal-based food production (Xu et al., 2021).

For calculating an exact carbon footprint related to nutrition, multiple questions would need to be answered by users, such as which type and how many different proteins they eat. For some users, it might be difficult, for example, to know the origin of the food and, especially, to estimate the amounts of the foods they consume. As the aim of the carbon footprint calculator is to be rather simple and to give a basic understanding of the users' carbon footprint, no product-specific questions regarding diet are asked. Instead, the average values of different diets at national levels are used, and users are only asked general questions about their diet and the amount of food they consume.

5.2. Inventory analysis

A study by Scarborough et al. (2014) presents GHG emissions for various diets in the context of the UK. In the CAMPAIGNers app, differences between various diets have been adopted from the study as percentages in relation to average national diets (table 5.1). The emissions are calculated for the daily intake of 2000 kilocalories, and the emissions include the life cycle from cradle to the retail store gate.

In the UK, the average woman consumes 2079 kcal/day and the average man consumes 2605 kcal/day. A healthy range of calories, however, varies between 1673–3011 kcal/day depending on age, gender, height, weight, and activity level. (SACN, 2011.) In addition, athletes can consume even more energy per day during their training phase and when competing, but the average energy intake is still only 2915 and 3156 kcal/day for women and men, respectively (Heydenreich et al., 2017). However, these values are only an average, and the amount of energy consumed may be different. Based on this information, users can choose whether they think they eat an average amount of food, or more or less than average (-25%, average amount, +25%, +50%).

Table 5.1: GHG emissions from various diets in the UK context and the difference rates in comparison to the regular eater.

Diet	Vegan	Vegetarian	Meat reducer [a]	Average eater [b]	High meat-eater [c]
GHG emissions [kgCO_2eq/a]	1055	1391	1705	2055	2624
Difference in comparison to regular eater	-49%	-32%	-17%	0	+28%

[a] Low meat-eater in the study (less than 50 g of meat daily)

[b] Medium-meat eater in the study (50–99 g of meat daily)

[c] High meat-eater in the study (more than 100 g of meat daily)

There are some uncertainties related to using diet-related carbon footprints for nutrition. For example, there is a lot of variation between the GHG emissions of different meats. Two users might eat the same amount of meat measured in grams, but one might eat poultry and one beef, which would make a difference in the carbon footprint.

There are also various studies that present different estimates for a person's annual carbon footprint related to nutrition. Hjorth et al. (2020) calculated an annual carbon footprint of 2467 kg CO_2eq (2000 kilocalories) for a Swedish person, whereas Sandström et al. (2018) calculated lower results: an annual footprint of 1070 kg CO_2eq for Europeans (variation between Bulgaria's 610 kg CO_2eq and Portugal's 1460 kg CO_2eq). This shows that there are differences in GHG emissions related to average diets between countries and studies.

Therefore, country-based GHG emissions are used for average diets in the app (table 5.2). Carbon footprints for average country-specific diets have been collected from various research papers and, therefore, they can be based on different system boundaries, assumptions, and initial data.

Table 5.2: Average GHG emissions of food consumed in a year per capita.

Country	Austria	Azerbaijan	Canada	Finland	France	Greece	Ireland
GHG emissions [$kgCO_2eq/a$]	1600 [a]	1200 [b, h]	2300 [b]	1800 [b]	1522 [c]	3000 [a]	2384 [d]
Country	**Italy**	**Lithuania**	**Peru**	**South Africa**	**Sweden**	**Turkey**	
GHG emissions [$kgCO_2eq/a$]	2010 [e]	2700 [a]	951 [f]	1700 [b]	2000 [g]	1200 [b]	

[a] Ivanova et al., 2017

[b] Akenji et al., 2021

[c] Vieux et al., 2012

[d] Hyland et al., 2016

[e] Pairotti et al., 2015

[f] Vázquez-Rowe et al., 2017

[g] Hallström et al., 2021

[h] Assumed to be the same as Turkey

5.3. Impact assessment

In the impact assessment phase, carbon dioxide equivalent (CO_2eq) emissions are calculated for users' nutrition. This is done by multiplying the country-based default annual GHG emissions from food consumption (table 5.2) by the diet's coefficient (table 5.1) and the amount of food consumed (equation 8).

$$CF_{food} = CF_{food,country} * (1 + c_{diet})*(1+c_{amount}) \quad [8]$$

, where CF_{food} is the carbon footprint of food consumed in a year (kgCO2eq/a)

$CF_{food,country}$ is the country-based carbon footprint of food consumed in a year

c_{diet} is the coefficient of the diet

c_{amount} is the coefficient for the amount of food consumed

As an example, the carbon footprint for a meat-reducer diet for a Finnish person eating more than the average can be calculated using equation 8:

$$CF_{food} = 1800\ kgCO_2eq/a * (1 + (-0.17)) * (1 + 0.25) = 1868\ kgCO_2eq/a$$

6. Other consumption

6.1. Goal and scope

In the CAMPAIGNers app, other consumption includes clothing, manufactured products, and leisure and services. In addition, GHG emissions from waste management are included.

6.2. Inventory analysis

The consumption of clothing, manufactured goods, and leisure and services cause different amounts of emissions per capita in different countries. Therefore, country-based values are used as a default value in the app (table 6.1). However, there is a big gap in studies relating to GHG emissions from other consumption. For example, the lack of timely studies causes distortion in the data pertaining to emission levels. In addition, the carbon footprints related to these other types of consumption have been collected from various studies, which are based on different system boundaries and initial data.

Manufactured products in Akenji et al.'s (2021) study include goods and materials that are for personal use, including home appliances, furniture, and daily consumer goods.

In Akenji et al.'s (2021) study, leisure includes activities outside of the home: for example, sports, culture, and hotel services. In addition, services include personal purposes: for example, insurance, cleaning, public services, and communication and information. In Ivanova et al.'s (2017) study, services include, for example, hotel and restaurant services, post and telecommunication services, education services, and health and social work services.

The users of the app are asked if they buy clothes and products or consume services more than or less than an average citizen in their country. If their consumption is less than the average, their carbon footprint from that category is reduced by 50%. If the user consumes more, the carbon footprint is increased by 50%.

Buying secondhand clothes and other products causes fewer GHG emissions than buying new ones. Therefore, users of the app can select whether they buy all or some of their clothes or other products secondhand. In the app, users can choose the share of clothes or products bought secondhand. Based on Gutowski et al.'s (2011) study, buying secondhand clothes causes life cycle energy savings of 63.5% on average. Therefore, if a user buys all clothes and products secondhand, emissions are reduced 63.5% from the values in table 6.1. This does not apply to leisure and services.

Table 6.1: GHG emissions per capita per year from clothing, manufactured products, and leisure and services.

Country	GHG emissions [kgCO_2eq/year]		
	Clothing	Manufactured products	Leisure and services
Austria [a]	500	1300	1500
Azerbaijan [b, c]	202	428	441
Canada [c]	929	1581	1400
Finland [c]	522	888	1101
France [a]	400	1300	900
Greece [a]	500	1100	2800
Ireland [a]	300	1200	2900
Italy [a]	600	1300	1700
Lithuania [a]	300	1100	600
Peru [d, e]	35	195	648
South Africa [c]	639	301	196
Sweden [d]	336	1745	2030
Turkey [c]	202	428	441

[a] Ivanova et al., 2017

[b] Assumed to be the same as Turkey

[c] Akenji et al., 2021

[d] Ivanova et al., 2015

[e] Average value for the Americas, excluding USA, Canada, Brazil, and Mexico

GHG emissions from waste management are included in the carbon footprint calculation. Waste management methods vary between countries. Waste can be recycled, incinerated, or landfilled. The average GHG emissions from waste management in the EU-28 countries in 2019 was 262 kgCO_2eq/capita (Eurostat, 2021a; Eurostat, 2021c). This value is used for all countries as a rough estimate.

6.3. Impact assessment

In the impact assessment phase, carbon dioxide equivalent (CO_2eq) emissions are calculated for users' other consumption. The calculation for clothes and manufactured goods is done by multiplying the country-based emissions by the purchase rate multiplier and the share of secondhand purchases (equation 9).

$$CF_{\frac{clothes}{products}} = CF_{\frac{clothes}{products},country} * (1 + c_{buy}) * (1 - c_{second}) \quad [9]$$

, where $CF_{clothes/products}$ is the carbon footprint of clothes or manufactured products ($kgCO_2eq/a$)
$CF_{clothes/products, country}$ is the country-based carbon footprint of clothes or manufactured products ($kgCO_2eq/a$)
c_{buy} is the share of how purchase amount differs from the average
c_{second} is the share of secondhand purchases

As an example, the carbon footprint for clothing in Canada, when the user buys less than the average and buys half of his or her clothing secondhand, can be calculated using equation 9:

$$CF_{clothes} = 929\ kgCO_2eq/a * (1 + (-0.5)) * (1 - 0.635/2) = 317\ kgCO_2eq/a$$

The calculation for leisure and services is done by multiplying the country-based emissions by the purchase rate multiplier (equation 10).

$$CF_{services} = CF_{services,country} * (1 + c_{buy}) \quad [10]$$

, where $CF_{services}$ is the carbon footprint of services and leisure ($kgCO_2eq/a$)
$CF_{services,country}$ is the country-based carbon footprint of services and leisure ($kgCO_2eq/a$)

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8 Appendices

Appendix I: City-specific bus and train emissions for lighthouse cities

	Bus		Train	
Lahti	28% diesel 33% electricity 39% biofuels	20 gCO_2eq/pkm	100% electricity	12 gCO_2eq/pkm
Dublin				41 gCO_2eq/pkm
Milan	87,5% diesel 12,5% hybrid	43 gCO_2eq/pkm	16,3% diesel 83,7% electricity	29 gCO_2eq/pkm
Freistadt				16 gCO_2eq/pkm
Linz	75% (85%) electric 25% (15%) natural gas	185 gCO_2eq/pkm	100% electricity	16 gCO_2eq/pkm
Trois-Rivières	74% diesel 26% hybrid	42 gCO_2eq/pkm		19 gCO_2eq/pkm
Vilnius	52% diesel 34% electricity 14% biofuels	28 gCO_2eq/pkm		12 gCO_2eq/pkm
Izmir	99,8% diesel 0,2% electricity	46 gCO_2eq/pkm	100% electricity	50 gCO_2eq/pkm
Skopelos	100% diesel			58 gCO_2eq/pkm
Malmö	10% electricity 90% biofuels	11 gCO_2eq/pkm	100% electricity	1 gCO_2eq/pkm
La Libertad (Trujillo)	100% diesel	46 gCO_2eq/pkm	100% diesel	32 gCO_2eq/pkm
Cape Town	100% diesel and petrol	42 gCO_2eq/pkm	100% electricity	43 gCO_2eq/pkm

- For hybrid buses, 50%-50% shares have been assumed for diesel and electricity.
- In Linz, electric buses are utilized on the most frequent bus routes. Therefore, an additional allocation has been made, and 10% more load has been allocated for electric buses.
- In Milan, electricity for hybrid buses has been produced by 100% renewables.
- **In Cape Town, emissions are calculated based on city-specific statistics. 83% of bus pkm are operated with minibuses and 17% with larger buses.**

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