

École polytechnique de Louvain

Carbon accounting tool for higher education students

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Nomenclature

ADEME Agence de la transition écologique

AWAC Agence wallonne de l'air et du climat

DHW Domestic hot water

EF Emissions factor

GHG Greenhouse gas

GWP Global warming potential

HEV Hybrid electric vehicle

IEA International Energy Agency

IPCC Intergovernmental Panel en Climate Change

MHEV Micro hybrid electric vehicle

PHEV Plug-in hybrid electric vehicle

PMC Plastic, metal, carton

Introduction

More and more people are becoming aware of the impact of human activities on the climate. Causing a drastic increase in greenhouse gases (GHG) emissions in the atmosphere, they lead to a climate disruption whose consequences are harmful to human life on Earth: rising global temperatures, water level, and frequency and intensity of extreme events (storms, flooding, etc.).

To control this imbalance, 196 countries signed the Paris Climate Agreement in 2015, aiming to limit the release of GHG to the corresponding global temperature increase of 1.5 degrees. In concrete terms, this means achieving climate neutrality (achieving net zero GHG emissions) by 2050. This international objective can be translated into an individual goal: everyone must limit himself to a carbon footprint, all direct and indirect emissions for which he or she is responsible, of 2 tons of CO_2 equivalents per year, the standard unit of measurement.

Several methodologies have been created to measure this footprint and establish its perimeter exhaustively. Furthermore, to be open to the general public, these methodologies are translated as a questionnaire on the individual's life, giving the user an estimate of his footprint once completed through emission factors, assumptions, and models. Multiple of these questionnaires are available on the Internet. However, they are focused on the life of a household or a worker, not that of a student. To address this lack, a partnership has been established with Factor-X, a small consultancy firm active in GHG accounting, and the *Agence wallonne de l'air et du climat* (AWAC) to create one with this target population.

To carry out its development, the methodologies are applied to a student's life and adapted into a narrative in the first person while considering the compromise between completeness and completion time. Indeed, the questionnaire must be adaptable to the variety of student profiles, while its completion remains below the 30-minute mark.

The questionnaire is divided into four modules: housing, mobility, food, and consumption. Based on Belgian, Walloon, and Brussels data, models are established to convert user inputs into emissions.

Finally, once implemented, its adaptability and completion time are tested through various student profiles.

Chapter 1

Carbon footprint

This first chapter aims to understand and specify the purpose of this master thesis. It starts by going through climate change, its harmful present and future consequences for life sustainability, and its causes: anthropogenic greenhouse gases (GHG) emissions.

To avoid or reduce those consequences, the question of responsibility must be addressed, and with it the GHG emissions accounting methods and existing tools.

1.1 Climate change and GHG emissions

Climate change has been increasingly observed worldwide for the last decades. Among the most notorious modifications, there are the sea-level rise, intensification of extreme phenomena (tropical storms, floods, droughts, etc.), retreat and melting glaciers, and increase of the global temperature (see figure 1.1); Many problems that have complicated consequences for human life and life in general on Earth, and that do not seem to diminish year after year.

To understand the causes of those issues, the United Nations Environment Programme and the World Meteorological Organization established the Intergovernmental Panel on Climate Change (IPCC) 35 years ago. Its missions were and are to "prepare a comprehensive review and recommendations with respect to the state of knowledge of the science of climate change; the social and economic impact of climate change, and potential response strategies and elements for inclusion in a possible future international convention on climate." [2]. Their first report in 1990 stated that *human activities may impact the climate*. After 30 years of research, they finally concluded in 2022 that *human activities are the main cause of the climate crisis*.

Indeed, climate change since the industrial revolution is not of natural causes, being deeply correlated to the amount of GHG in the atmosphere. And this amount is only increasing yearly due to human activities (see figure 1.2).

In two centuries, the proportion of CO_2 in the air, the primary GHG, went from 280 ppm, a value stable during more than 6000 years, to 414.7 ppm in 2021 [3], a rate last reached

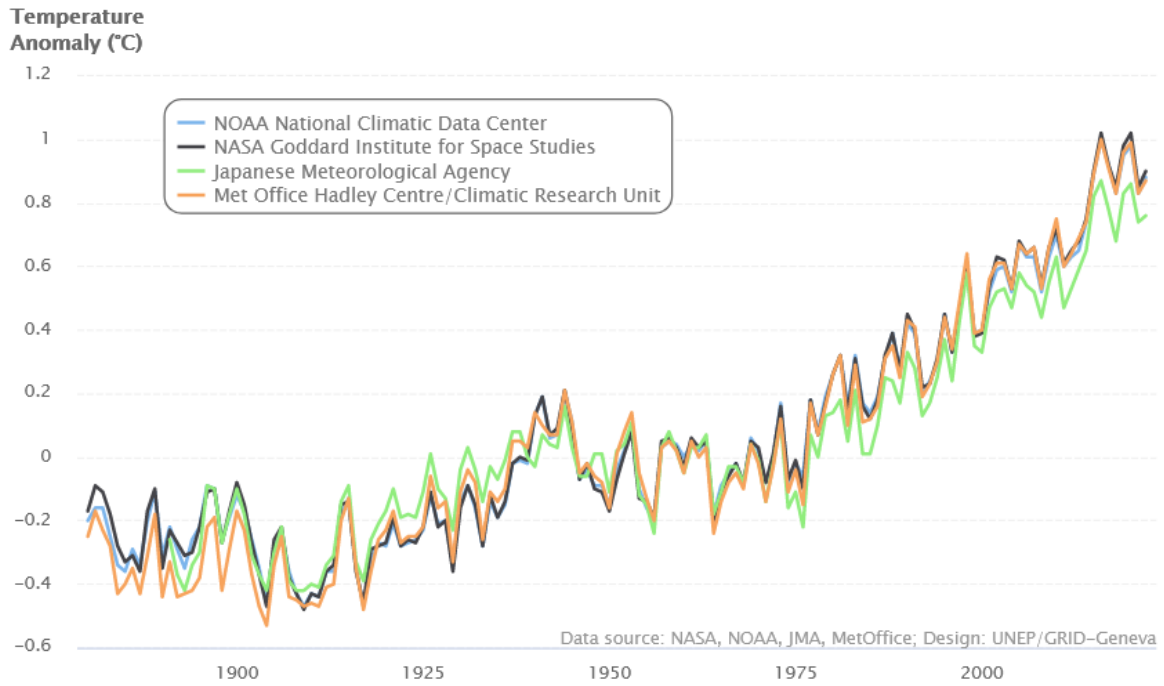


Figure 1.1: Global surface temperature between 1880 and 2022. Four independent data sources show nearly identical long-term warming trends based on the 1910-2000 average. From [1]

one million years ago in an Earth with 3-4 higher global average temperature and ocean 15 meters above today's level.

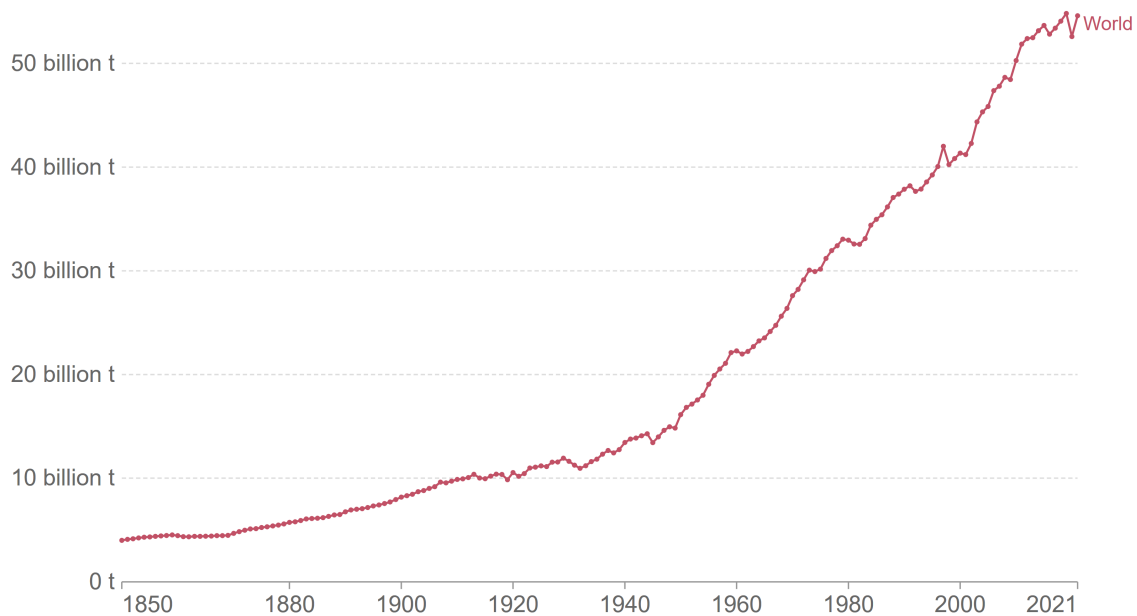


Figure 1.2: Annual world GHG emissions evolution since the industrial revolution, from [4]. *GHG emissions include carbon dioxide, methane, and nitrous oxide from all sources, including agriculture and land use change. They are measured in carbon dioxide-equivalents over a 100-year timescale.*

Furthermore, the IPCC does not only describe and explain the present situation. It also prepares probable future scenarios to try predicting the climate change evolution in the

years to come, built from plausible developments in society over the 21st century, from the greenest to the worst in terms of emissions. Here is looked at five of the narratives from their 2021 report [5]. In figure 1.3 can be seen the different evolution of temperature and in figure 1.4 the corresponding annual emissions of different GHG.

In short, the five scenarios displayed are (from [6]):

1. SSP1-1.9: Scenario to represent the 1.5°C goal of the Paris Agreement
2. SSP1-2.6: Sustainable development scenario
3. SSP2-4.5: Intermediate scenario
4. SSP3-7.0: Regional rivalry scenario
5. SSP5-8.5: Fossil-fuel based development

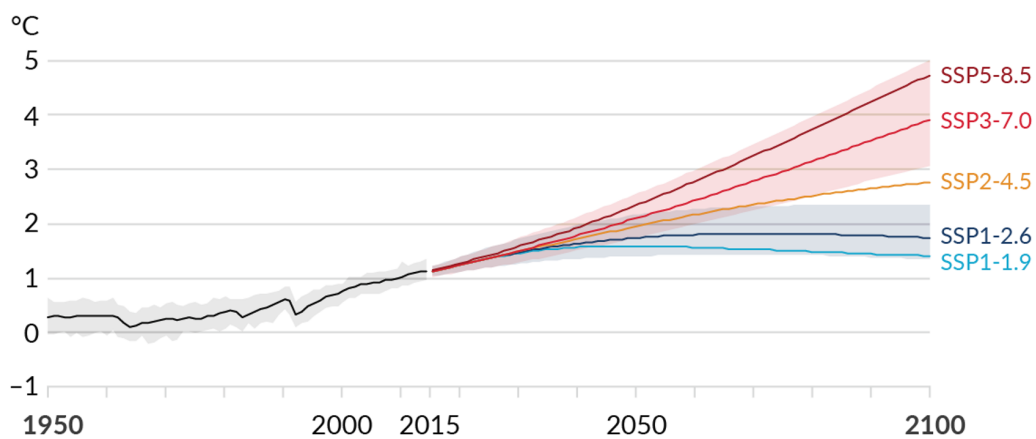


Figure 1.3: Global surface temperature change relative to 1850-1900, across five illustrative scenarios, from [5]

Looking at the most pessimistic scenario (SSP5-8.5), which reflects the continuity of primary energy consumption, it would lead to more than four degrees elevation of global temperature by 2100. This translates to harmful consequences such as inundation of coastal cities, unprecedented heat waves and substantially exacerbated water scarcity in many regions, irreversible loss of biodiversity, etc. (from [7]).

Nobody can know the future. However, some scenarios still appear more probable than others, given the evolution of the world. According to [8], the intermediate scenario (SSP2-4.5) and the two pessimistic (SSP3-7.0 and SSP5-8.5) are likely to happen, while the two optimistic (SSP1-1.9 and SSP1-2.6) expected a peak of emission around 2020 and therefore they are less probable since it did not occur.

Nevertheless, 196 countries ratified the Paris Agreement for the climate [9] in 2015, with the aim of the SSP1-1.9 scenario, i.e., limiting global warming to 1.5 °C above pre-industrial levels.

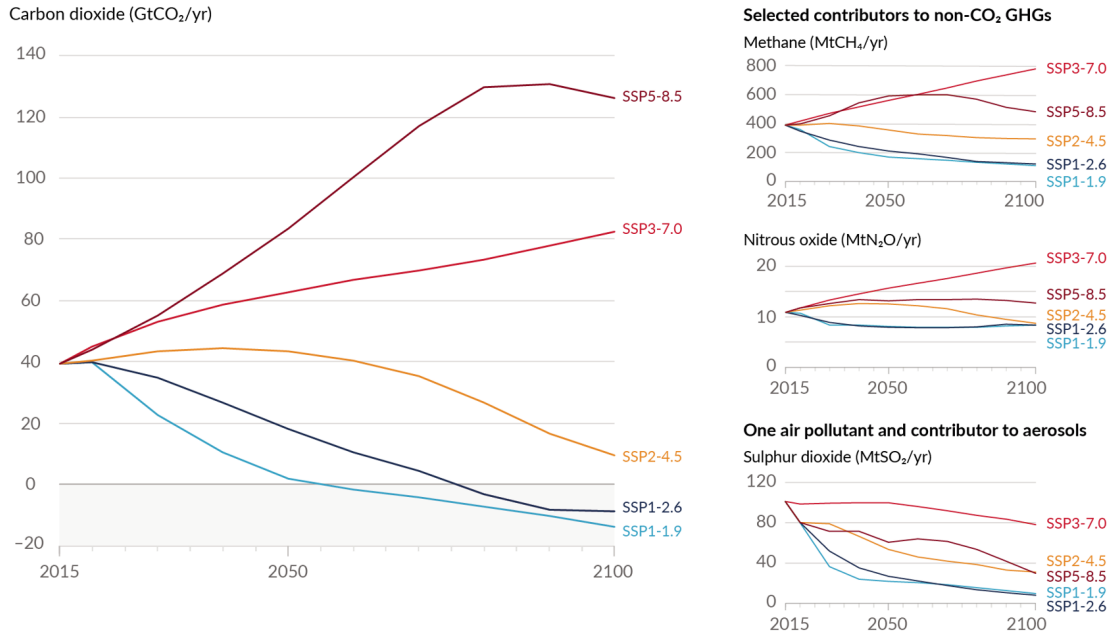


Figure 1.4: Future annual emissions of CO_2 (left) and on a subset of crucial non CO_2 drivers (right), across five illustrative scenarios, from [5]

Even if the first years since the agreement did not meet the agreement's expectations, in the European Union, this objective is still translated concretely with two targets: a 55 % net reduction of GHG emissions by 2030 and total climate neutrality by 2050 [10]. This means an annual 5% decrease in emissions until 2050.

However, to reduce emissions, it is first mandatory to know what to reduce. As seen in figure 1.4, they are multiple GHG participating in climate change.

1.1.1 Type of GHG

The most famous GHG is certainly CO_2 . While it remains the main one, it is not alone. The IPCC lists as GHG [11]: methane CH_4 , nitrogen dioxide NO_2 and fluored gases (CFC, HCF, etc.).

The problem is to be able to rightfully compare them to understand what is the most urgent emission to avoid. As they are different compounds, comparing only the quantities of emissions in mass or volume would not be correct to weigh their effects, as they have other lifetimes in the atmosphere and radiative forcing.

This differentiation of characteristics calls for a standard scale to allow fair comparison. This is why has been established the unity *equivalent carbon dioxide* CO_2e , based on the global warming potential (GWP), which is, from [12]: "a measure of how much infrared thermal radiation a greenhouse gas added to the atmosphere would absorb over a given

time frame, as a multiple of the radiation that would be absorbed by the same mass of added carbon dioxide."

In other words, GWP measures the warming a gas creates compared to CO_2 . As CO_2 is given a GWP value of one if a gas had a GWP of 10, then one kg of that gas would generate ten times the warming effect of one kg of CO_2 . Also, this warming can be stated over different timescales, usually over 100 years. To compute CO_2e over 100 years, each gas is multiplied by its GWP over a 100-year timescale (GWP100).

To illustrate, once scaling all gases in the same unit, it gives for territorial emissions in Belgium the share shown in figure 1.5.

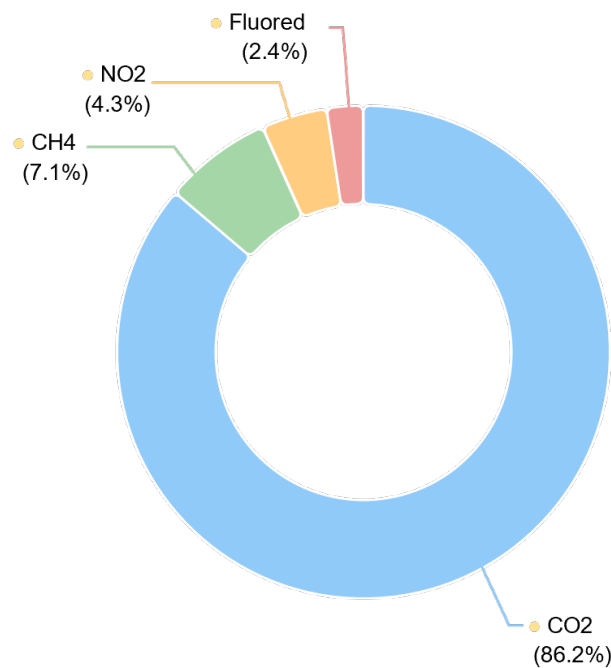


Figure 1.5: Distribution of greenhouse gases territorial emissions per type in Belgium in 2021, from [13]. They are measured in tonnes of carbon dioxide-equivalents over a 100-year timescale

Now that it is understood what is required to diminish and why, the following questions would be who is involved and how to cut them off.

1.2 Origin and responsibility

To understand who is involved, a start could be to look at the division of the GHG territorial emissions between different sectors in Belgium shown in figure 1.6. As is exposed, the sources are numerous and concern multiple aspects of society: industry, transport, residential heating, etc. No z action, enterprise, or person is responsible for the emissions: everyone emits some GHG through multiple activities.

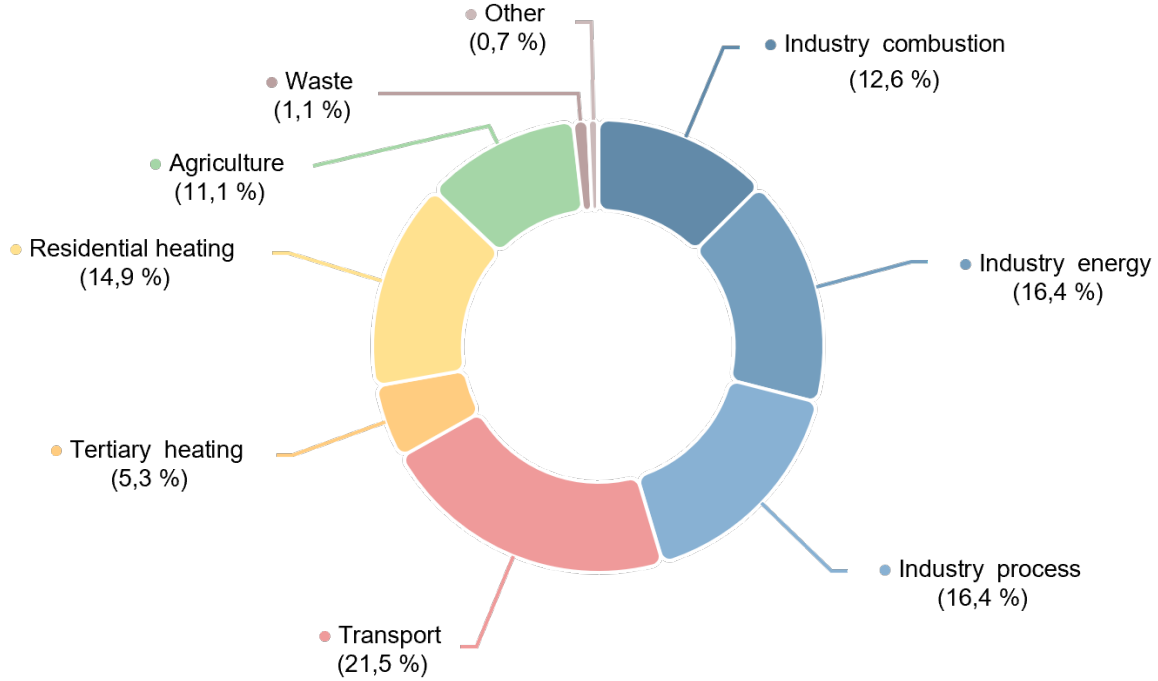


Figure 1.6: Distribution of greenhouse gases territorial emissions per sector in Belgium in 2021, from [13].

Moreover, this figure only accounts for *direct* emissions. But to describe individual responsibility, a broader look should be given: For example, if someone buys a car that was built in a foreign country, even though he did not emit any GHG and it is not accounted for in the country's territorial emissions, he should be accounted responsible for its GHG releases (mining, manufacturing, transport to Belgium, etc.) as he is the one to benefit it.

This divides personal GHG emissions into *direct* and *indirect* ones. In this example, *direct* emissions are caused when using the car (assuming a thermal engine), while *indirect* emissions are produced during production, importation, and later end-of-life treatment.

Then, instead of asking who is involved as everyone is, a better question would be: what is one's responsibility?

1.2.1 Difference between carbon emissions and carbon footprint

In Belgium, carbon *direct* emissions are estimated between 4 and 10.5 tonnes of CO_2e per inhabitant depending on the region and the study, and carbon *footprint* between 10 and 20 tCO_2e/hab [14, 15].

The previous example can explain the difference between the two estimations: it depends on what is considered. In the first, only *direct* territorial emissions are considered (i.e., transport, heating, industry, etc.), while in the second *indirect* emissions are also regarded

(i.e., GHG emitted by non-resident companies in the production of goods and services delivered to the final demand of the country's residents).

To compute coherent results for a personal footprint, which can be seen as one's responsibility, it is necessary to define the limits of what needs to be accounted for. To help in this endeavor, several methodologies were created.

1.2.2 Carbon footprint measurement methodologies

Across the world, various measurement methodologies are today available to frame carbon footprint calculations. The GHG Protocol [16] and the *Bilan Carbone* [17] are two of them. The first was established in 1998 in partnership with the World Resources Institute and the World Business Council for Sustainable Development to "establish an international standard to calculate the emissions of an organization's value chain" [18]. The second was created in 2004 by the *Agence de la Transition Écologique* (ADEME) [19] to "quantify the greenhouse gasses of individuals and organizations" [18]. Although they are both internationally recognized and in practice very close [20], the GHG protocol is more globally spread, while the Bilan Carbon is mainly applied in France. For that reason, the GHG protocol has been chosen to validate the model.

The ISO 14064 (from the International Organization for Standardization) [21] is sometimes cited as another methodology to follow as it is the international standard addressing the "quantification and reporting of greenhouse gas emissions and the verification of this information"[22]. In fact, it performs another complementary function. From [22]: "The difference between these two documents¹ is that the GHG Protocol identifies, explains, and provides options for GHG inventory best practices, while ISO 14064 establishes minimum standards for compliance with these best practices. Though different in a few minor areas, the protocol and the ISO standard are complementary documents with ISO identifying what to do and The GHG Protocol explaining how to do it [...]."

Either way, this choice of methodologies does not drastically change the output of this thesis: they differ slightly from each other, but lots of similarities can be found, making them overlap (see appendix B, comparing the two methodologies and the ISO 14064).

With the choice made, we next need to investigate the functioning of the GHG protocol.

1.2.2.1 GHG protocol

The GHG protocol introduced the system of scopes [16] with three levels: scopes 1, 2, and 3. They are described in figure 1.7. Even if the scopes are illustrated for an activity, they can be used for individuals, too (it is developed in more detail in section 2.2.2).

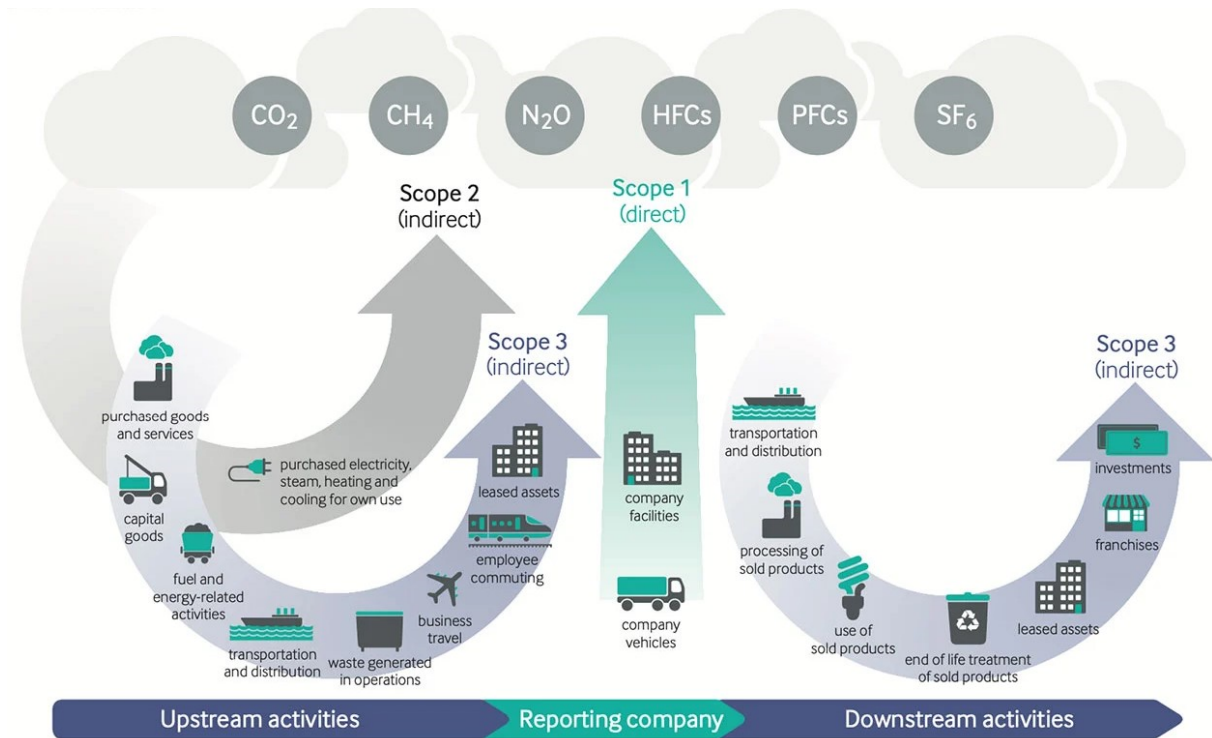


Figure 1.7: GHG protocol scopes and emissions across the value chain for an activity, from [23]

The carbon footprint can be described as the look onto the three scopes, attributing all GHG emitted throughout the production process to the person who consumes the goods and services. Those are the limits chosen for individual responsibility in this study.

Nevertheless, stays the second question: how to reduce the emissions?

The first step to answer it is to understand what is each personal footprint composed of.

Similarly to dividing the country's direct emissions into different sectors, it is possible to divide an individual's carbon footprint into several aspects. This is where a questionnaire is needed to translate a person's life into the weight of CO_2e per year. With this value, a comparison can be made to the Paris Agreement's objectives: to stay below the 1.5°C limits, each person would have to meet an annual carbon footprint of 2 tons by 2050.

1.3 Existing calculator

Following the system of carbon footprint and existing methodologies, several questionnaires are available online to help the user compute and understand his emissions. The principle is to ask the user for information about his everyday life (transportation, food, consumption, housing, etc.) and translate it through hypotheses and emission factors (see 2.2.1) to a mass of CO_2e , usually per year to get the annual footprint of the user.

¹The GHG protocol and ISO 14064

In French, multiple surveys already exist: *MyCO2* [24], *Nos gestes climats* [25], *AWAC* [26], *RTBF* [27], etc.

Every questionnaire differs from each other by choices, hypotheses, and objectives. Indeed, to compute the entire user footprint precisely requires a large amount of information about the user's life. As it is impossible to collect the whole data due to lack of time or too high complexity, each questionnaire takes different approaches: some are focused on time completion like *RTBF*, trying to give a rough estimation in a survey of fewer than 10 minutes; some like *myCO2* and *AWAC* concentrate on the narrative aspect of the survey, to accompany more the user to be able to request more precise information; others like *myCO2* and *Nos gestes climats* are based on French behavior and habits; etc.

However, they all have a common ground: they are built for workers or households. There is a lack of representativeness of the student population in the different existing surveys²

Though, in Belgium, about 30 % of the population has a higher education diploma [28], and currently, there are more than 200 thousand higher education students in Wallonia and Brussels [29].

Thus, an agreement was reached with *AWAC* to create a narrative suited for French-speaking higher education students in Belgium.

²During the writing of this thesis, *myCO2* has published a new questionnaire for students. Nevertheless, it is elaborated for French students, who have different habits than students in Brussels or Wallonia.

Chapter 2

Carbon footprint questionnaire

With the primary goal defined, the next step clearly states the objectives pursued and the constraints faced. This means understanding the targeted audience, compromising between time and precision, and clarifying the purposes of this questionnaire.

Then, the way to associate them with the GHG protocol's standards must be specified. Finally, to start the elaboration, the main structure is built, and closer attention is given to the formulation specificities together with the tool designed by AWAC.

Once everything is set up, the development of the questionnaire can begin with the different conversion models to kg_{CO_2e} of the user's various actions and habits.

If the reader feels like putting himself (again) in the shoes of a student for half an hour, he can try the questionnaire directly at the address <https://awac-factorx.b12-consulting.com/app/home> and compute the carbon footprint he would get.

2.1 Objectives and constraints

To build a proper questionnaire, several aspects must be clarified: which public the survey is addressed to and what should contain its footprint, how much time and what type of exhaustiveness is wanted, and most importantly, the purpose sought.

2.1.1 Targeted audience

First, the targeted audience of the survey is the *high education French students in Belgium*. In practical terms, it includes the majority of students in Wallonia and part of the student in Brussels, which means that the data collection model should be based on those two regions.

Moreover, the type of information requested must be in line with the expected knowledge of the general student public. For example, many students have never paid their electricity or gas bills. This leads to further hypotheses to estimate their consumption (see 2.4.3.2)

instead of asking directly for the value. The goal is not to infantilize the user but to offer him alternative answers in case of non-knowledge of the information. Nevertheless, the ones who know precisely those pieces of information should always get the chance to enter them to correct the model's estimation. This guideline will define a lot of the questionnaire making: asking for data sufficiently large so that the vast majority of users can answer without having to confabulate while still adequately chosen to be able to model the targeted value (area, consumption, distance, etc.) properly and always letting the opportunity to clarify the estimation made.

Also, high education student years can be considered a transition period between youth and adulthood: the student gains more and more autonomy regarding their family household but still stays more or less dependent on it. This raises the question of what is of his responsibility and his lever arms in terms of emissions. For example, is he responsible for the shopping habits of his parents? He still benefits from it but can hardly make any changes to it; Additionally, some habits can be better understood only once the choice is available for the user (e.g., someone is expected to be more aware of his electricity consumption once he pays the bills). For those reasons, the *responsibility perimeter* of the questionnaire has been chosen following the capacity of the student to choose to adapt to different students' profiles and avoid random answering.

Finally, the formulation also will be adjusted to appeal more to the age and style of the user (with an expected age between 18 and 25 years, the vocabulary and style can be different from targeting older generations)

2.1.2 Compromise between time and precision

Second, the questionnaire must be finishable within 15 to 30 minutes. More than 30 minutes would bore the user and lead to incompleteness and mid-course abandonment.

This entails constant compromise between precision and time of completion. Here, precision refers to the capacity of the questionnaire's estimations to approximate the user's real lifestyle, i.e., to be able to differentiate several behaviors, virtuous or harmful in terms of GHG emissions.

This compromise leads to applying a particular focus on the diversity of student profiles to limit the number of questions for each while still being exhaustive. For example, one of the main differences is the availability and usage of a flatshare, meaning that the user may combine two housings. The user who does have one has logically less information to give and so can afford more precision on his sole housing; meanwhile, for the user who divides his year into two housings, several assumptions should be made to avoid over-timing the housing section.

2.1.3 Purposes

Third, it is evident that the student coming to the survey already have some sensibility to GHG emissions. The purpose of it all is not to quantify to the gram the user footprint, as it would be an impossible task: even with an extended time limit, it would be impossible to categorize and specify every aspect of someone's life; also, even if it was possible to describe everything, the EF used to translate the behaviors in carbon footprint are teemed with uncertainty when they are up to date or available.

The idea is to allow the user to understand, in order of magnitude, the impact of his choices and to see what change of behavior could lead to decrease his footprint. The goal is to make students aware of the reality of their GHG emissions habits. To do so, the questioning must be able to adapt to the diversity of students' profiles.

Those concerns must be kept in mind while creating the calculator: it must be in line with the three scopes but at the same time realistic. This leads to the decision to simplify the calculator (compared to a fully exhaustive one) to stay accessible to the general public. However the methodologies still needs to be applied. This is what is discussed next.

2.2 Methods

To build a conform yet attractive questionnaire, it needs to comprise every type of GHG and answer to the GHG protocol's scopes applicable to an individual footprint (as mentioned in 1.2.1) while still adapting to the audience.

The first requirement is achieved thanks to the EF, and as for the second, different choices must be made given the relevance of the different posts of the scopes.

2.2.1 Emission factor

The emission factors, or EFs, are the basis of the calculator. They allow conversion from a distance, mass, energy, etc., to CO_2e mass. Furthermore, they account for every type of GHG¹ and translates them to the equivalent carbon unity.

However, these EFs are not absolute: they all contain uncertainty and have a date of validity.

To generalize several aspects (e.g., the EF of a pair of jeans instead of the pair of jeans of a precise brand, the annual average national electricity EF instead of local and instantaneous, etc.), assumptions must be made, leading inevitably to uncertainty that can vary

¹Water vapor, essentially of natural origin, is excluded from the IPCC list of GHG. However, it also highly contributes to the greenhouse effect. It is why, for some exceptions (when it makes sense in order of magnitude, mainly for plane's drags), the EF chosen takes it into account

between 10 to 80 % or even more. This is why the result of a carbon footprint should be considered as an order of magnitude instead of an exact result. Yet, the choice has been made not to explain it to the user as it could be misunderstood and misleading to the general public.

Furthermore, EFs are computed according to the practice at a given time. If those practices change, the EF should be updated to remain correct.

Moreover, EFs are expensive: it costs around 20 000 euros to compute the EF of one product [30]. Fortunately, some databases have free access, like the one from the ADEME, a French public establishment.

ADEME's database

The majority of EFs in this work comes from the ADEME database: *Base Empreinte*.

It is, according to [31], the official public database of EFs and inventory datasets needed to conduct corporate carbon accounting and environmental signage of consumer products and services. It forms a rich source of centralized data, which is extremely practical.

Nevertheless, many EFs are French-centered and Belgian data does not always exist. When it is the case and when it is relevant to look to regional EF (e.g., for electricity factor), the method applied is to first look for the European (RER) value. If it is not available also, then the French value is chosen.

2.2.2 Completeness to methodologies

For the questionnaire to give valid results, it must respect existing methodologies to be exhaustive.

The methodologies followed here are of the GHG protocol, with its three scopes: *direct* emissions, *indirect* emissions linked to energy use, and other *indirect* emissions. In turn, every scope subdivides into *posts*, focusing on different categories of each scope. They can be observed in figure 1.7. To be exhaustive, every post should be taken into account.

Yet, as explained before, being complete *to the gram* is impossible in terms of time and information. For that reason will be looked upon each post to see if it is relevant or not, and if so, what would it includes concerning a Belgian French-speaking higher-education student life. All posts do not necessarily apply to describing a student's footprint. For example, *use of sold product* in the third scope in the downstream activities hardly makes sense for the ordinary student, as he is not considered a creator or seller of any goods and services; Moreover, the pertinent posts still need to be converted to the student lifestyle. The review of the different posts is summarized in table 2.1.

Nevertheless, presenting the questions to the user in the order of the GHG protocol posts does not seem appropriate. As explained in the table, some posts intersect with each other. Therefore, in addition to meeting the objective of responding in a limited and user-friendly way, we include the narrative aspect in the questionnaire.

Table 2.1: Relevance and translation of the 19 posts of the GHG protocol for a student carbon footprint accounting tool.

Scope	Post description for a company	Relevance	What emitting activities it includes if relevant / Why ruled out if not
1	1. Direct emissions linked to facilities	Yes	Primary energy domestic heating and hot water system (gas, oil, etc.) (even if the student usually doesn't <i>own</i> his housing)
	2. Direct emissions linked to vehicle owned or controlled by the company	Yes	User's commutes and trips if he drives a vehicle
2	3. Indirect emissions linked to electricity consumption	Yes	Domestic electricity consumption Use of electric vehicle
	4. Indirect emissions linked to vapor, heat or cold consumption	No	Neglected due to preponderance of stationary combustion or electricity consumption for an individual's heating and cooling requirement.
3	5. Purchased goods and services	Yes	Every good the student might purchase: Food, devices, clothes, furniture, etc. For services, digital consumption.
	6. Capital goods	Yes	Housing and own or shared vehicles
	7. Fuel and related energy-related activities	Yes	This cuts across the different parts concerning fuel or electricity consumption, namely post 2,3 and digital services
	8. Upstream transportation and distribution	Yes	Transportation, importation and distribution of products purchased assets
	9. Waste generated in operation	Yes	Domestic wastes
	10. Business travel	Yes	Post 10 and 11 could be joined together to contain every transport the student might do: academic commute, daily trip, hobbies, vacations, etc.
	11. Employee commuting	Yes	Together with post 6, housing and vehicles can be considered as <i>leased</i> assets, as students rarely own them themselves
	12. Upstream leased assets	Yes	Students are considered as final scale consumers, meaning that they do not create or sell any goods or services. Downstream activities are then neglected
	13. Downstream transportation and distribution	No	Same as 13.
	14. Processing of sold products	No	Same as 13.
	15. Use of sold products	No	Same as 13.
3	16. End-of-life treatment of sold products	No	Same as 13.
	17. Downstream leased assets	No	Same as 13.
	18. Franchises	No	Same as 13.
	19. Investments	No	Students are assumed not being in charge of investments, or in possession of such domain

2.3 Narrative and structure

To appeal to the user, the questionnaire follows a narrative line in the first person. This leads to some attention on the formulation and to adapt to the tool designed by AWAC.

Here is the narrative main structure:

When the user starts the questionnaire, a short introduction appears, explaining briefly the carbon footprint, the unity CO_2e used to measure it, and the perimeter looked upon (the text is available in appendix A).

Then, the user is directed to a new page where the questionnaire begins. Using the AWAC resources (see 2.3.2), it is divided into six modules (the main categories), and each of them is, in turn, subdivided into several sub-modules. The structure is displayed in figure 2.1.

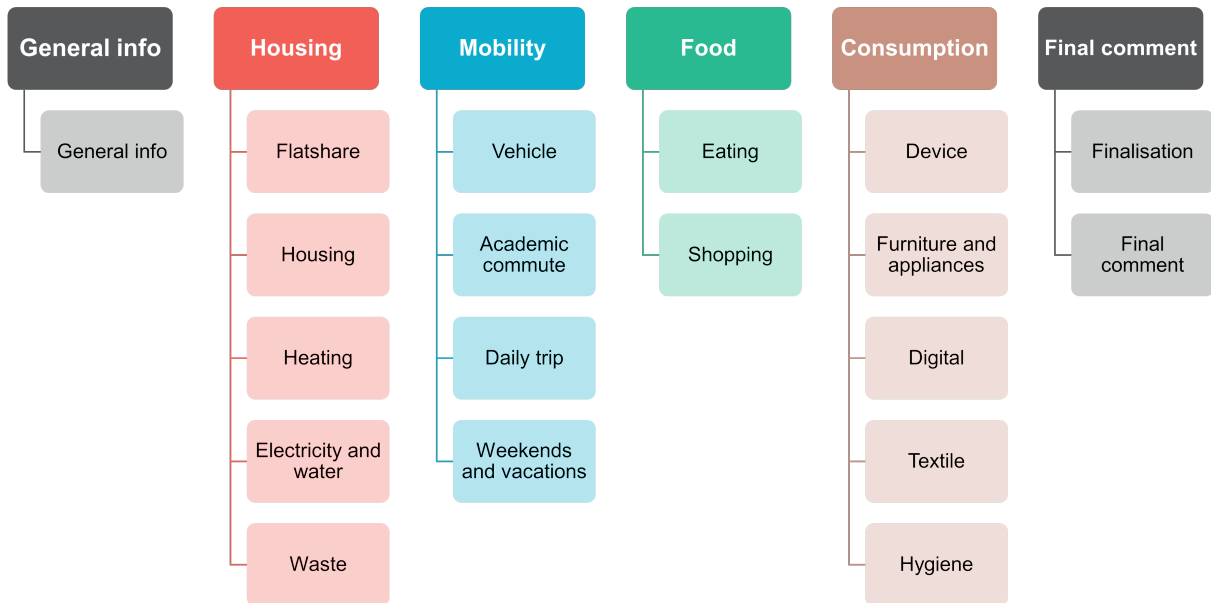


Figure 2.1: Questionnaire modules and sub-modules across the narrative

The first and final modules don't compute emissions; they aim to introduce and conclude the questionnaire. Thus, the student lifestyle is split into four categories: housing, mobility, food, and consumption. The user goes linearly from one to another. This is essential as many questions and estimations depend on previous answers.

An example of submodule is shown in 2.2

Besides storytelling and first-person writing, other rules must be followed to produce a proper survey.

Kot

Je kotte .i

Lors des cours, je suis au kot en moyenne 5 nuits par semaine.

Pendant mes périodes de blocus et d'examens, je ne suis que rarement à mon kot.

Je ----- mes congés (Pâques, été,...) au kot (quand je suis en Belgique).

- passe la totalité de
- passe la majorité de
- passe la moitié de
- ne passe que rarement

Figure 2.2: Example of sub-module, questions and answers with the sub-module *Flatshare*. In blue is the title of the sub-module, and in cyan the answers.

2.3.1 Formulation's specificities and user mindset

Several points must be considered, from the formulation of questions to the type of information requested.

For the questions' wording, as answers are in the form of holes in sentences, the user needs to understand quickly what is expected. For example, if a frequency or behavior specific to a period is asked, the timescale or period should be displayed before the answer or just after (like in the first question of the example, with "*lors des cours*"); Moreover, the statements should be clear and must not be open to interpretations.

Concerning the type of information, the user should have easy access to it and be comfortable being asked about it (e.g., for investment, people could be reluctant to give the amounts they possess); Furthermore, the data searched should make sense in the questionnaire logic: it must be either essential to model and estimate some aspects of the student life relevant in terms of scale (the idea is not to waste 15 questions for a change in grams of CO_2e at the end), either to include a summary of what the user may consider as emitting. Indeed, although some posts are several orders of magnitude higher in terms of the amount of CO_2 emitted (e.g., take the plane VS buy a nightstand), the goal is to help the user understand the impact of certain behaviors.

Of course, this elaboration is impossible without analyzing the AWAC calculator's rules.

2.3.2 Awac calculator

As previously mentioned, an agreement was reached with AWAC to create the narrative. An exposition of the display is visible in figure 2.3

The tool used has a fixed number of modules (6), which explains the narrative structure, and a variable number of sub-modules; In addition to the questionnaire display, the tool also possesses several valuable functionalities:

- A result system and an *action mode* letting the user return to the survey and see the effect of changes on his footprint. This will be used in the results 3.
- *Advanced* and *infomode* questions: they are *hidden* questions exhibited to the user only if he clicks on the relevant icons (respectively a wrench and info point). This is useful for avoiding misinterpretation and letting user corrects estimations if needed.

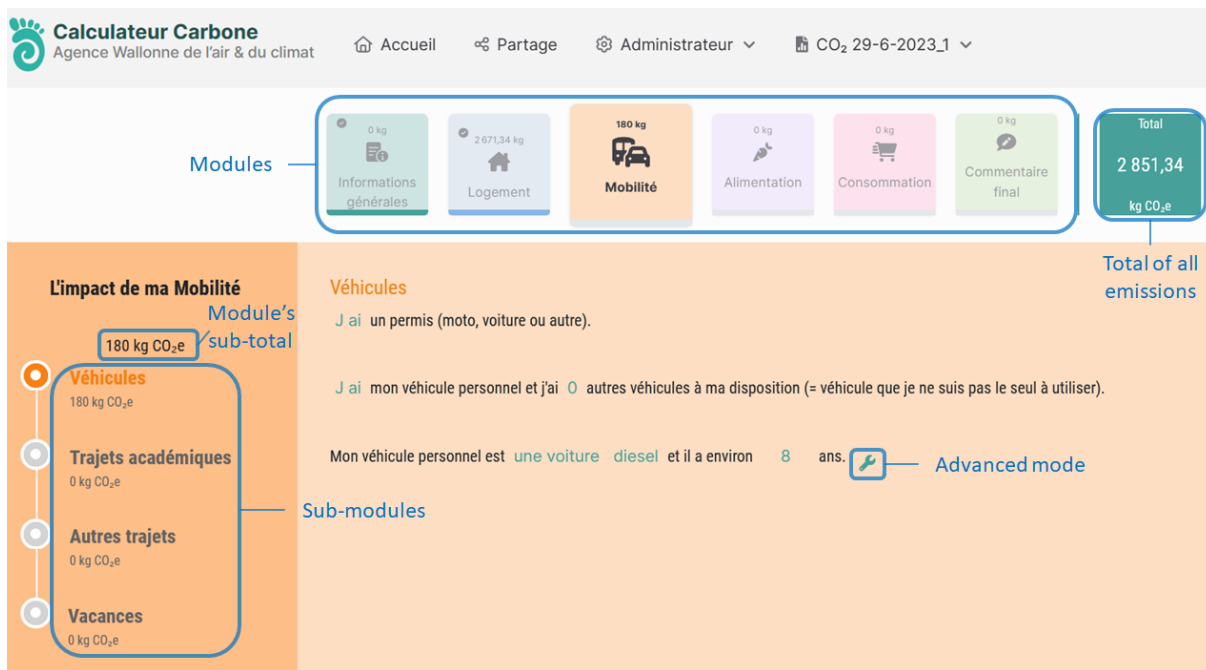


Figure 2.3: Display of the tool from AWAC

To conclude this section, in figure 2.4 can be observed the links between the different posts of the GHG Protocol representing the association of narrative and exhaustiveness.

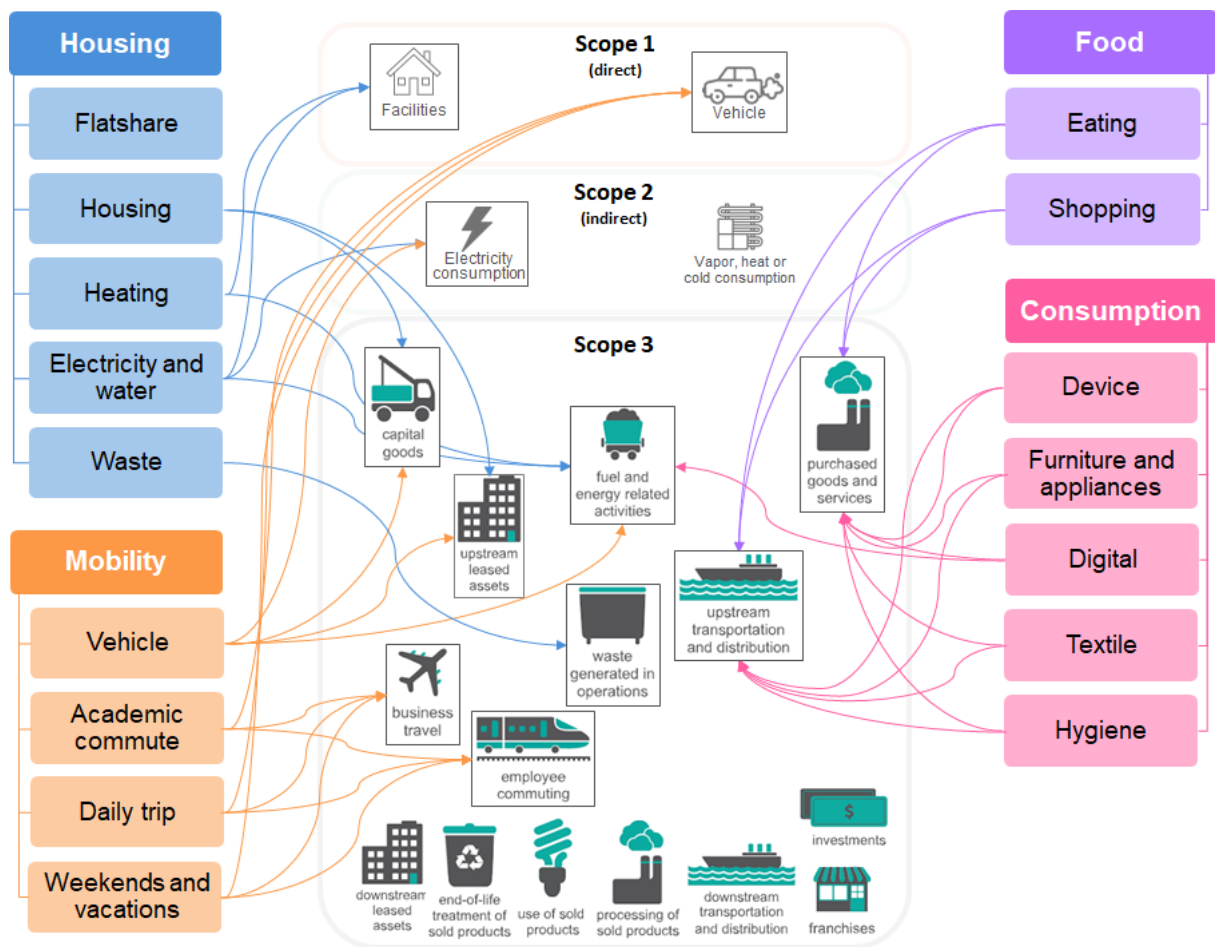


Figure 2.4: Links between GHG protocol's posts and scopes and questionnaire sub-modules

2.4 Questions and conversion

This section highlights the different calculations and hypotheses that allow the questionnaire to shift from the user's answer to the equivalent CO_2 weight.

It is by far the most significant part of the thesis. It has for objective to display all the questionnaire and to explain both the diversity of profiles taken into account and the reasoning behind the carbon impact computation.

2.4.1 Approach and legend

A nomenclature has been implemented to make the reading as easy as possible: the questionnaire is seen from module to module and from sub-module to sub-module.

In each sub-module, questions are first exposed with an example of filling with a screenshot of the website². However, a fundamental aspect of the questionnaire is the dependence of questions on previous answers, which change or appear according to certain conditions. For that reason, for each sub-module, a condition tree was built to show every possible question and to display the form as its whole while exposing the different possibilities and the carbon model it entails.

In each question, the variables it contains are listed and described afterward in tables. There are five different types of variables:

1. Variables called *number* where the user enters a numerical value. They will be preceded by a **X** in the questions.
2. The *dropdown* displays a drop-down menu for the user. They will be preceded by a **D**, and their choices are summarized in the different variables' descriptions.
3. The *text* leaves a free textual input to the user and is noted **T**.
4. The *hypothesis* adapts the text to the user, on which he has no choice. they are marked by **HYP**.
5. The *estimation* containing results of previous answers and assumptions. In some cases, the user can correct it if he can give a better value. It is announced with **EST**.

Finally, every explanation will use the masculine to talk about the user.

To illustrate, with the beginning of sub-module *Textile* of the *Consumption* module: display, conditions, and description is available on figure 2.5, 2.6 and table 2.2 respectively.

²These examples are not linked to each other, meaning that all put together, they do not represent a coherent questionnaire.



Figure 2.5: Textile formulation

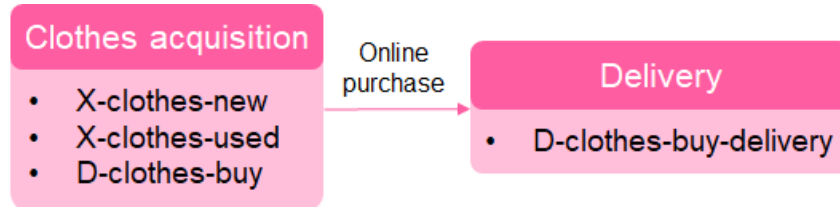


Figure 2.6: Textile conditions

In the conditions, the arrow between the two questions specifies a condition relationship: if in the first question named *Clothes acquisition* the user indicates purchasing his clothes online (by selecting the *online* option of **D-clothes-buy**), the second question named *Delivery* appears to him. The answers in the display 2.5 do not comply with this condition, so the second question is not shown.

The conditions will always be above the arrows and summarized in a few words for clarity of the schematic.

Table 2.2: Textile variables

Variables name	Description
X-clothes-new	Numbers of clothes bought new in the last 12 monts
X-clothes-used	Numbers of clothes bought used in the last 12 monts
D-clothes-buy	Place of the clothes's purchase (shop, hand to hand, online)
D-clothes-buy-delivery	Place of the delivery (home, relative's home, relay point)

2.4.2 General Information

This first module aims to start the narrative side of the questionnaire. The answers here do not impact the result and serve the sole purpose of making the questionnaire more personal to the user. Therefore is asked for the name with **T-name**, the age with **X-age**, and the type of the higher education institution with **D-school**.

Figure 2.7: General information formulation

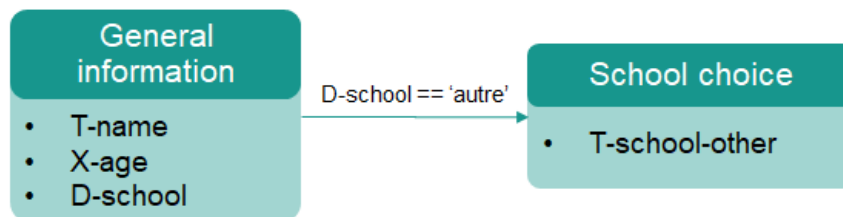


Figure 2.8: General information conditions

Table 2.3: General information variables

Variables name	Description
T-name	Name of the user
X-age	Age of the user
D-school	Type of high education institution (University, <i>haute école</i> , other)
T-other	Name of the type of the user institution

Regarding the **D-school** variable, it is common in Belgium to divide higher education institutions into two categories: university and non-university [32]. Many of the latter are considered "haute école"; however, some students cannot find themselves in those choices. To leave open the addition of new terms is let the opportunity for the user to enter his institution denomination, which will be afterward added to the existing list.

2.4.3 Housing

As its name implies, this module covers the emissions linked to student housing, from the cost of building construction, heating, electricity, and domestic hot water to household waste.

Housing has a major impact on the final energy consumption as it represents one-fourth of the total consumption in Wallonia [33]. For a student who may use two different housings (family household and flatshare), this module is of prior importance for his footprint.

Besides, it is the module where the most diverse answers and situations are expected from the students, and this is for several reasons:

First, there is a distinction between those using a flatshare³ and those staying at their parents' accommodation (in Brussels, the former accounting for 70% of the student population [34]).

Second, there is a diversity of flatshare types, from one-person single apartments to 15 people dorms.

Third, the time allocation between the flatshare and the family household varies tremendously, from the student staying on campus only during the courses and returning home every weekend and vacation to the almost completely independent student returning to their family only for holidays.

All those aspects need to be considered to make the questionnaire suitable for every student profile; However, the time constraint invites us to avoid unnecessary questions. For example, an exhaustive description of the parent housing of a student going back only two days per month might not be useful. In contrast, a more complete description of the flatshare might be better for the validity of the different estimations of the module.

Finally, to generalize to the public, the precision of the answers needs to be restrained, considering that some students may have never taken care of bills themselves. It leads to the creation of a hypothesis to facilitate the completion (e.g., categories of housing area 2.4.3.3) and alternatives in case of lack of knowledge (e.g., "I don't know" option in heating device 2.4.3.4), while still giving the opportunities for those who seek high precision to correct the results (e.g., possibility to manually enter meters 2.4.3.6).

This module begins by determining if the user has use of a flatshare. If yes, it also specifies his time distribution between the two dwellings.

³To avoid any misunderstanding, "flatshare" stands here and in the rest of the section for the student housing (commonly denominated *kot* in Belgium), and the "household" is considered as the primary residence, usually the family home. It means that if a student is entirely independent of his family, he will not have a flatshare, just a household

2.4.3.1 Flatshare

The first sub-module aims to understand the flatshare behavior of the user, i.e., for one year, the allocation of the time spent in the household and in the flatshare. Consequently to the type of splitting, the user will be categorized to adapt the rest of the section to his profile to optimize the number of questions asked.

To do so, the year is distributed into three academic periods: courses, exams, and vacations. The user might behave differently between those periods (e.g., a student staying all week in his flatshare during the classes but never going during vacations). By asking the user's behavior for each of them, we can compute the proportion of the year (later *Proportion*) the user stays in his flatshare.

With this number, he will be placed into one of the three categories described hereafter.

A. Distribution of the year

To model this sharing, as said before, the academic year has been divided into three parts: classes, study time and exams session, and vacations.

For the modeling to be effective, the 52 weeks contained in a year must be allocated to one of those parts, and this assumption needs to be as broad as possible for every higher education student, whether it comes from a university, an *haute-école* etc. Table 2.4 shows this distribution across a sample of different institutions.

Table 2.4: Distribution of the 52 weeks of an academic year into courses, exams, and vacations period. (1) Has been chosen not to take into account the second exam session and consider it as vacation, as it is highly variable among students. (2) Christmas holidays were accounted for in the exams period, as it is generally a time dedicated to study.

Institution	Type	Course	Exams ⁽¹⁾	Vacation ⁽²⁾
ULB [35]	University	27	10	15
UCLouvain [36]	University	27	11	14
ULG [37]	University	28	10	14
Umons [38]	University	28	10	14
Conservatoire de Bruxelles [39]	Haute école	28	11	13
ECAM [40]	Haute école	27	10	15
Condorcet [41]	Haute école	27	11	14
ENCBW [42]	Haute école	25	12	15
Hénallux [43]	Haute école	27	12	13
Average (rounded)		27	11	14

Although the table 2.4 contains only a sample of institutions of the *Fédération Wallonie Bruxelles* (out of more than 250 *hautes écoles* [44]), a certain recurrent distribution over the three categories can be extracted. The average (rounded) of the sample will be used in the questionnaire to divide the year.

B. Proportion computation

The next step is to find a way to allocate those portions of the year to the time spent in the flatshare and in the household. For this purpose, the user has access to four questions, three of which are for each part of the academic year. They can all be seen in figure 2.9. The conditions and variables are in figure 2.10 and description in table 2.5.

Kot

Je kotte .i

Lors des cours, je suis au kot en moyenne 5 nuits par semaine.

Pendant mes périodes de blocus et d'examens, je suis à moitié à mon kot.

Je ne passe que rarement mes congés (Pâques, été,...) au kot (quand je suis en Belgique).

Figure 2.9: Flatshare formulation

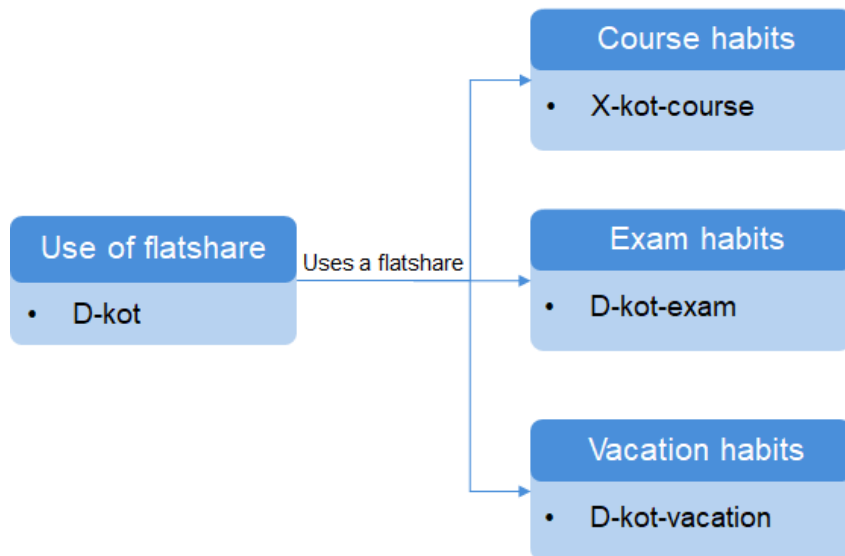


Figure 2.10: Flatshare conditions

The methods of computation for the courses differs from exams and vacation.

For the course period the calculation is straightforward: **X-kot-course** gives the number of nights per week spent at the flatshare. Then it remains to divide it by seven and multiply it by the number of weeks of courses to get the part of the *Proportion* linked to the courses.

Table 2.5: Description of flatshare’s variables and hypothesis

Variables name	Description
D-kot	If the user has use of a flatshare (yes, no)
X-kot-course	Number of nights at flatshare during courses
D-kot-exam	Time spent in flatshare during exam (All time, majority, half, rarely, never)
D-kot-vacation	Time spent in flatshare during vacation (All time, majority, half, rarely, never)

For the two others (exams and vacations) **D-kot-exam** and **D-kot-vacation**’ drop-downs need conversion to factors before multiplying with their distribution. They are displayed in table 2.6.

Table 2.6: Conversion of textual answers into numerical factors for year share

Answer	All time	majority	half	rarely	never
Factor	1	0.85	0.5	0.15	0

Thus, for example, for a user who would answer respectively *5*, *rarely*, and *never*, the computation will be:

$$Proportion = \frac{\frac{5}{7} \cdot 27 + 0.15 \cdot 11 + 0 \cdot 14}{52} = 40.3\% \quad (2.1)$$

C. Categorization

Once the proportion is computed, the user will be attributed to a specific category. Three categories have been chosen: enough to increase the consideration of different profiles while avoiding over-complexity.

- **Category 1:** $0 < proportion < 50$ % of the year spent at the flatshare. It includes those who do not have a flatshare and those who spend most of their time in the household.
- **Category 2:** $50 \leq proportion < 80$ % of the year spent at the flatshare. It represents the students who live mainly in their flatshare while regularly returning to their households.
- **Category 3:** $80 \leq proportion \leq 100$ % of the year spent at the flatshare. It accounts for the almost completely independent student.

For the category **1** (if the user has use of a flatshare), the flatshare questions are alleviated, while the household part is more exhaustive.

For the category **2**, it is the opposite: the flatshare part is more exhaustive, while the household is alleviated.

Finally, For the category **3**, there will be no part about the household.

With that attribution, now can be discussed the rest of the housing's models

2.4.3.2 Amenities

The three next sub-modules (housing, heating, and electricity and water) are deeply related to each other. They are only separated to respect a certain narration in the questionnaire, asking first everything about the type of building and the inhabitants, then about the heating device and preferences, and finally about the electricity consumption and the use of domestic hot water (DHW).

Before explaining the different questions asked and the hypothesis behind them, here is an overview of the overall structure.

The purpose is to find and quantify the different energy vectors use in kWh per year of the housings to convert it into kg_{CO_2e} . To do so, four main housing's energetic-consuming sources are looked upon: heating, DHW, appliances, and cooking.

For the first is required a description of the heating system, area, state, number of inhabitants, and temperature preferences of the dwelling. Those pieces of information are split between the *Building* 2.4.3.3 and *Heating* sub-module 2.4.3.4. The three other sources are covered in the *Electricity and water* sub-module 2.4.3.5 with the DHW system and total electricity consumption.

Moreover, an energy carrier must be allocated to each source to apply the correct EF. The carriers are gas, fuel oil, electricity, and wood (Their EF is displayed in table 2.12).

Every housing does not work with all four carriers, and all the sources cannot work with every vector. The distribution possibilities are described in table 2.7. To optimize the number of answers requested to the user, we need first to make some assumptions about which combination to take into account.

Table 2.7: Existing energy carrier for the energy consuming sources of a household.

/Posts Vectors/	Heating	DHW	Cooking	Appliances
Gas	X	X	X	
Fuel oil	X	X		
Electricity	X	X	X	X
Wood	X	X	X	

There are in theory 32 combinations of posts and vectors for every housing. However, these distributions are not equiprobable: for example, there are many more homes with a gas boiler for heating and DHW with an electric stove than homes with wood for heating, fuel oil for DHW, and a gas stove.

The idea is therefore to focus the choices on what is most common so as not to overload the housing module. For example, there is no question about the cooking post, as it is considered to be solely working with electricity, as it is the case in 68% of Belgian habitation [45].

In addition, to achieve the best possible balance between exhaustiveness and completion time, different choices and assumptions will be proposed for each category (**1**, **2** and **3**), described below:

For the flatshare

- Category **1** and **2**: the choice of the system for heating and for the DHW is sum up to one (like in 74% of Belgian household [45] which use the combined system).
- Category **3**: here, the flatshare being the residence in which the student stays in the majority, and no other questions being asked about a second home, the precision for the requested information increases. Three answers are expected: the heating system, the system for the DHW, and the potential presence of an electric auxiliary heater.

For the household : The housing diversity being considered higher than for the student flatshares, it has been decided to separate the category **1** and **2**.

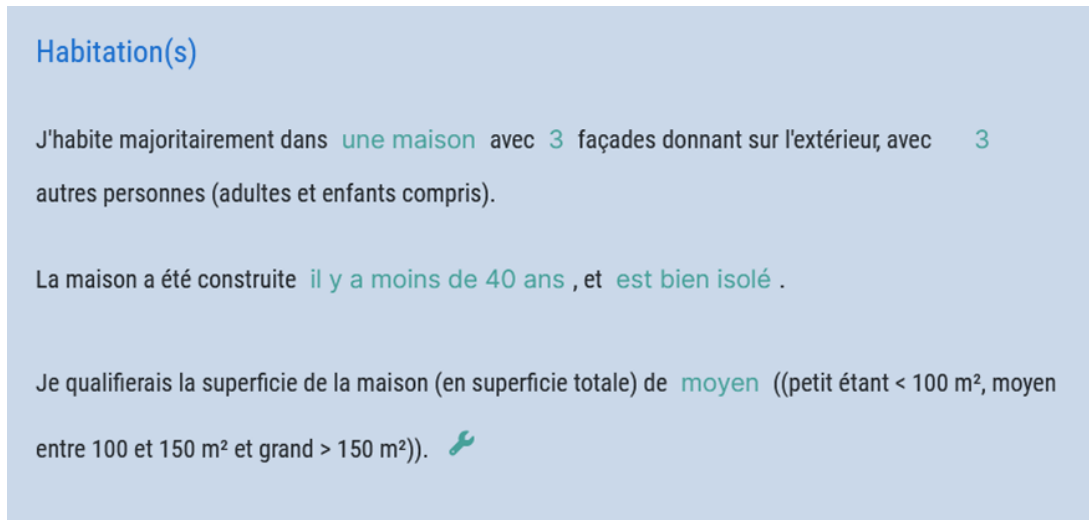
- Category **1**: similarly to the category **3** for the flatshare, three pieces of information are expected: the system for the DHW, the heating system, and the potential presence of an electric auxiliary heater. This category also includes those who don't have a flatshare and therefore require an exhaustive description of their various heating systems.
- Category **2**: only a heating system is required to limit the questionnaire length for this category.

Once the different vectors for each post have been decided, it remains to quantify the different vectors' use per year. This is done through various models, explained hereafter.

2.4.3.3 Building

In this second sub-module is concatenated the information about the flatshare and household building.

This sub-module begins with an explanation of the different variables and questions and continues with detailing the area model and the consideration of the buildings' carbon footprint. Its display is found in figure 2.11, the conditions in figure 2.12⁴ and the description of the variables in table 2.8.



The screenshot shows a light blue background with the title 'Habitation(s)' in blue. Below it, there are three lines of text with user input in green. The first line says 'J'habite majoritairement dans une maison avec 3 façades donnant sur l'extérieur, avec 3 autres personnes (adultes et enfants compris)'. The second line says 'La maison a été construite il y a moins de 40 ans , et est bien isolé .'. The third line says 'Je qualifierais la superficie de la maison (en superficie totale) de moyen ((petit étant < 100 m², moyen entre 100 et 150 m² et grand > 150 m²)).' followed by a green wrench icon.

Figure 2.11: Building formulation

The data provided can be divided into three main types: first, info about the area, which will influence the heating and the cost of the building; second, about the number of inhabitants, which plays a part in several computations (heating, electricity, appliances, wastes, etc.) to share the emissions between all the beneficiaries; third, precision about the state of the building, which then enable to find the heating requirements. The latter infos will be described in detail in the next sub-module.

In *Flatshare size* and *Household size*, the living area is not requested as a number. Instead, the variable **D-kot-size** and **D-habit-size** are: small, medium, and large. As this value is impacting the whole module, and given the lack of knowledge the user might have on this matter (during beta-testing, almost every user had never asked themselves what the answer was, and so had to approximate by themselves, which can lead to significant inaccuracy), this method was chosen to avoid any wrong estimations. Still, with the *advancedmode*, a user who knows the answer or disagrees with the estimation given can correct the estimated value with **EST-kot-size** and **EST-habit-size**.

⁴As can be seen, the two parts (flatshare and household) have lots of similarities. For this reason, in this sub-module and the following, they will be described jointly when possible and then given the difference between the two to avoid redundancies.

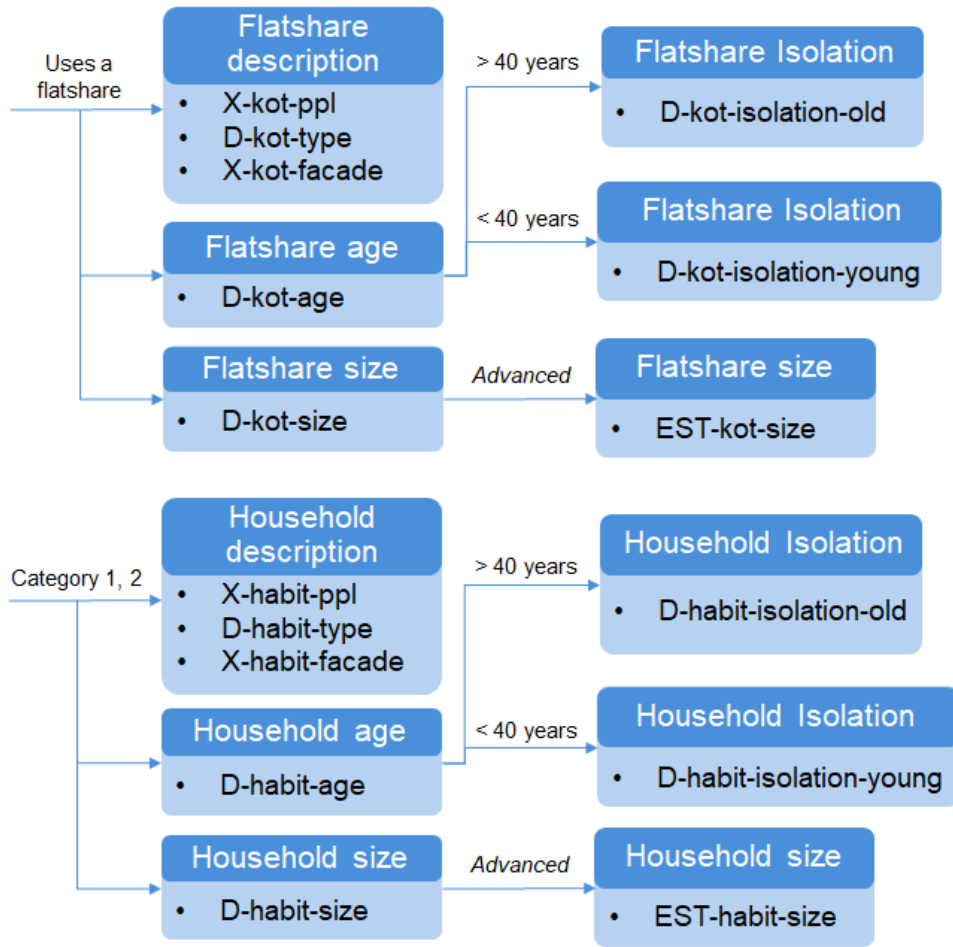


Figure 2.12: Building conditions

The differences between the two parts are the following: "*majoritairement*" in the *Household description* is mentioned to palliate the users who have more than one household (e.g., students with separated parents), to focus is made on the principal household; **X-habit-ppl** takes into account adults and children, which means that children and adult will be considered as equal in the sharing of emissions.

With all those pieces of information, a model has been created to correctly estimate the area and the CO_2e mass of the construction of the building.

A. housing area

As stated before, the idea is to estimate as correctly as possible the area of the household and the flatshare based on three criteria: the type (apartment or house), the number of people sharing the place (assuming that every person has their own personal room) and an estimation of the size (small, medium or large).

Although it is common to see mean values used for households (with the average household of two parents and two children), it is a different story for the flatshare since it covers a single apartment for one person to flatshares of 15 students sharing a kitchen, living

Table 2.8: Description of building's variables

Variables name	Description
X-kot-ppl	Number of people living in the flatshare
D-kot-type	Type of flatshare housing (house, appartement)
X-kot-facade	Number of ext. facades of the flatshare
D-kot-age	Age of the flatshare' building (<40 years, >40 years)
D-kot-isolation-old	Flatshare isolation if >40 years old (reisolated, not reisolated)
D-kot-isolation-young	Flatshare isolation if <40 years old (good isolation, bad isolation)
D-kot-size	Estimation of flatshare area (small, medium, large)
EST-kot-size	Area of the flatshare (m^2)
X-habit-ppl	Number of people living in the household
D-habit-type	Type of household housing (house, appartement)
X-habit-facade	Number of ext. facades of the household
D-habit-age	Age of the household' building (<40 years, >40 years)
D-habit-isolation-old	Household isolation if >40 years old (reisolated, not reisolated)
D-habit-isolation-young	Household isolation if <40 years old (good isolation, bad isolation)
D-habit-size	Estimation of household area (small, medium, large)
EST-habit-size	Area of the houshold (m^2)

room, and water rooms. This is why two models are used: one dependent on the number of inhabitants and type of housing for flatshares, and one dependant only on the type of housing for households.

Flatshare model First, the flatshare model is based on the norms of student housing. As housing norms are a matter of region, the ones from Brussels can be distinguished from those from Wallonia.

In the former, it is stated that the minimal housing area must be at least 12 m^2 for a single person and 18 m^2 for two flatmates [46]. Moreover, they are multiple rules to follow when renting a student collocation (without accounting for the bathrooms and toilets) [34]:

- Each private space for exclusive use must have a minimum net floor area of 12 m^2 ;

- The minimum area of the joint space for food preparation and living must be at least for an occupation of: 28 m² for 2 to 5 students; 32 m² for 6 to 9 students; 36 m² for 10 to 12 students.

In Wallonia, a student housing must respect the minimal norms of liveable area [47], which state [48]:

- The minimal dimensions of the entire housing must be at least 15 m² for 1 person (or 24 if built after 2008), 28 for 2, and then 5 m² in addition for each new person (33 for 3, 38 for 4, etc.).
- for the individual room: only 4 m² under 2.2 m of ceiling are necessary for the bedroom of 1 person.

These standards are pretty low. Following the rules strictly, a building could be named a student collocation for ten people with only 68 m² of area, or not even seven square meters per person.

Since the norms of Wallonia seems permissive, it has been decided to base the model on the one from Brussels' norms for flatshare of two or more. For single apartments, the 24 m² value of Wallonia's norms.

Nevertheless, it's essential to bear in mind that those recommendations are not always followed, as there are shortages and scarcity in student housing ([34, 49]). Some prefer to live in non-regulatory accommodations to make up for the prices.

To include this reality in the model, the norms for the minimal liveable area are accounted as the *medium* size in the questions⁵. *Small* and *large* estimations are respectively decreased and increased in relation to the medium assumption.

The assumptions can be found in table 2.9: each estimation has a specific room size which is multiplied by the number of inhabitants; for the joint space, a compliance factor is applied to the minimal standards⁶. In figure 2.13 can be seen the results of this model.

Table 2.9: Flatshare area categorization description

Name	Room size (m ²)	Compliance factor w/ standards
Small	9	0.75
Medium	12	1
Large	13	1.25

⁵to be able to model up to 15 flatmates, an extrapolation is made, with 40 m² from 13 to 15 students

⁶For single apartment, the 24 meters squared of minimal standards are assumed to be 12 m² for the room and 12 m² of shared space.

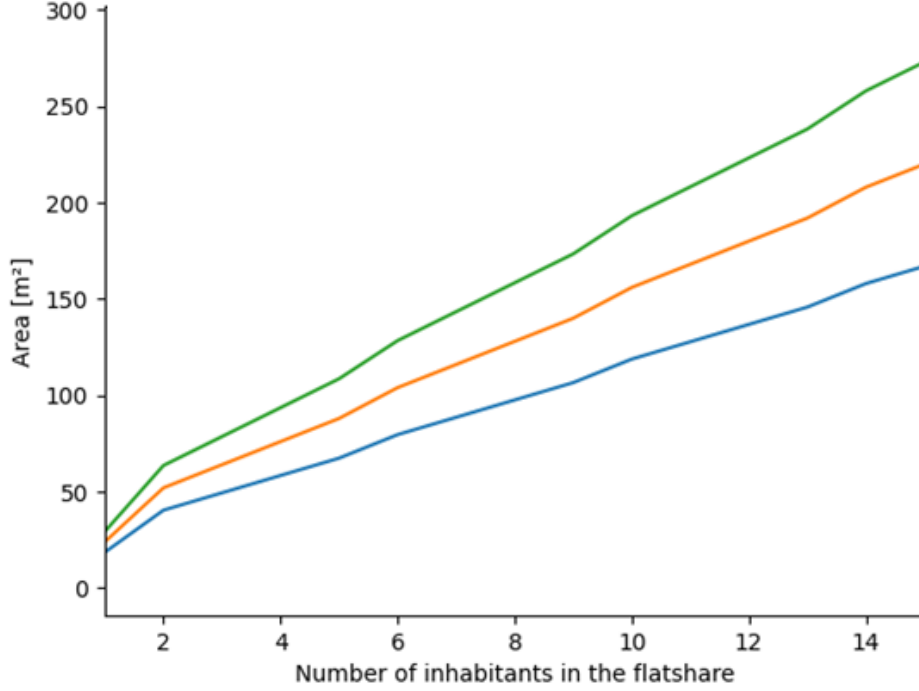


Figure 2.13: Flatshare area estimation depending on the number of inhabitants and the estimated size of the user. In blue *small*, in orange *medium*, and in green *large* estimation.

Household model Second, concerning households, the model is based on the national average housing area. It is not the number of people living together that matters, but the type of habitation: an average apartment is 67 m², and an average house has 125 m² of liveable area [50].

Equivalently to the flatshare partition, the average is considered as *medium*, where *small* and *large* are the medium correspondent multiplied by a factor of 0.75 or 1.25. The results are shown in table 2.10

Table 2.10: Household area categorization description

/Type Name/	House m^2	apartment m^2
Small	90	50
Medium	120	67
Large	150	85

Those values of small, medium, and large areas computed are always displayed in the question to the user so that he may choose one of the three estimations consciously, as can be seen in figure 2.11.

B. Age and weight of the building

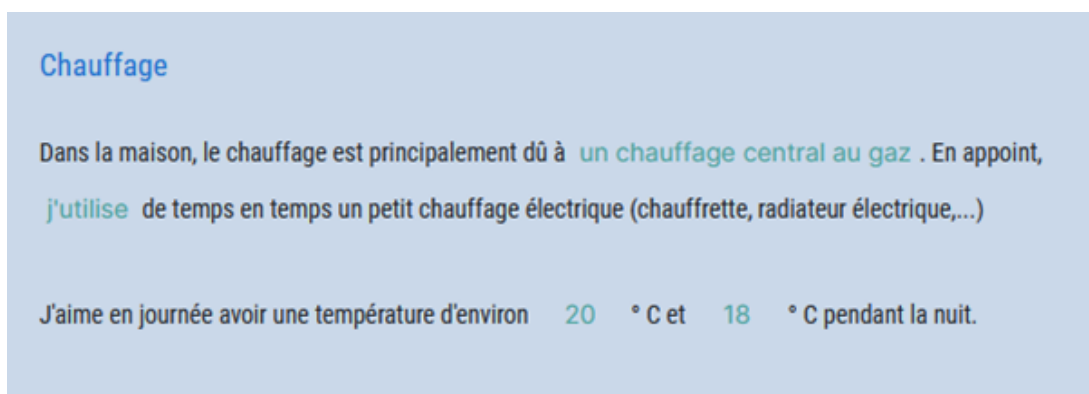
The 40 years cut of **D-kot-age** and **D-habit-age** serves two purposes. On one part, it is linked to data found about the Belgian house stock and BEP (Building Energy Performance) [51], which leads to further hypothesis for the heating consumption (see section 2.4.3.4). On the other part In this case, it also determines if the building is amortized or not. If it is younger, it is not yet fully amortized, which means that the user needs to account for part of the building footprint on his own.

As it is difficult to know precisely the age of the building, the amortization is assumed to be linear over the years. The EF (equal for apartments and houses, given in kg_{CO_2e}/m^2) is multiplied by the area and is divided by 40 and by the number of inhabitants.

For this computation, we do not consider the distribution of the year (*Proportion*), as it doesn't matter if the place is occupied to add the emissions. Even if a student decides to be 90 % of the time in his household, it will be accounted for a full 40th of the construction emissions of his flatshare.

2.4.3.4 Heating

The heating sub-module is not extensive in terms of questioning. Only is asked the heating system (the number of systems required depending on the category of the user) and the heating preferences, as can be seen in figure 2.14. In figure 2.15 can be seen the influence of category on the possible questions. Again, the variables are explained in table 2.11. Still, in this section will be explained the model to estimate the energy consumption per year and its allocation to the proper vector with the impact of every variable not yet explained in the last part; Also, the model implemented to handle the housing combinations (flatshare and household for those concerned) will be exposed.



Chauffage

Dans la maison, le chauffage est principalement dû à **un chauffage central au gaz** . En appoint, j'utilise de temps en temps un petit chauffage électrique (chauffrette, radiateur électrique,...)

J'aime en journée avoir une température d'environ **20** °C et **18** °C pendant la nuit.

Figure 2.14: Heating formulation

Both housings share the same type of questions: *Heating system* to specify the type of heater; *auxiliary heating* to add the influence of a small electrical auxiliary heater; Temperature preferences during day and night.

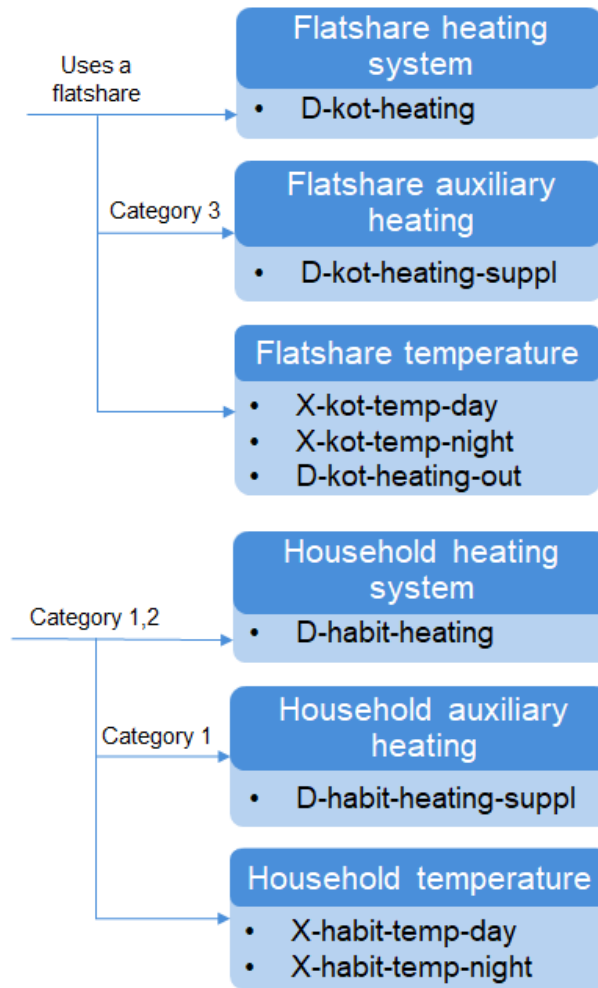


Figure 2.15: Heating conditions

Table 2.11: Heating variables description

Variables name	Description
D-kot-heating	Flatshare heating system (elec, gas, fuel oil, wood, heat pump, don't know)
D-kot-heating-suppl	Use an auxiliary heater in flatshare (yes, no)
X-kot-temp-day	Flatshare Temp. during day
X-kot-temp-night	Flatshare Temp. during night
D-kot-heating-out	Habits of flatshare heating when away (no change, decrease, stop)
D-habit-heating	Household heating system (elec, gas, fuel oil, wood, heat pump, don't know)
D-habit-heating-suppl	Use a auxiliary heater in household (yes, no)
X-habit-temp-day	Household Temp. during day
X-habit-temp-night	Household Temp. during night

Small point of attention with **D-kot-heating-out** which, for its part, asks the user's behavior with the flatshare heating when he leaves it.

For example, if nothing is changed even if nobody resides in the flatshare during the weekends, then the student will have to add to his emissions the accumulation of heating in the household and in the flatshare at the same time.

This behavior is not asked for the household because the assumption was made that when the student leaves the household, there are still people living in it, so the heating emissions will not be accumulated.

With all the information collected, can be built the model to estimate the heating need per area over a year.

A. Energy consumption for heating in kWh/m²/year

For the model's estimation to be coherent with the actual building heat consumption, it is first grounded on the BEP statistic of the Walloon real estate [52].

The BEP certification of a building consists of a global assessment of a building's energy performance based on a defined calculation method factoring in multiple aspects summarized in 2.16. The output given is the specific primary energy consumption per year and per area, which categorizes the housing into one of 9 groups (see 2.17), following the result (e.g., group C if the output is between 170 and 255 kWh/m²/year) [53].

Naturally, Being as exhaustive as an entire BEP certification would be impossible in the questionnaire. This is why the model is built to roughly estimate the *housing BEP* from its age and state of isolation. Then the result is refined with a *construction factor* based on the type of the building and the number of exterior facades, and a *preference factor* based on the heating habits of the user.

A.1 BEP estimation The objective is to give the user's housing one of the BEP. To do so, a decision tree is created where the age and state of isolation allow to differentiate the buildings.

The first division is about the building age: older or younger than 40 years. As mentioned, the 40 years limit is chosen according to [52]. This report divides Walloon real estate into three groups: buildings after 1984, between 1971 and 1984, and before 1971. By grouping the two lasts, the real estate can be divided in two, with 1984 as the tipping point, i.e., buildings of more or less than 40 years.

Then, the degree of isolation plays a part in the final BEP level attribution.

- Older than 40 years old:

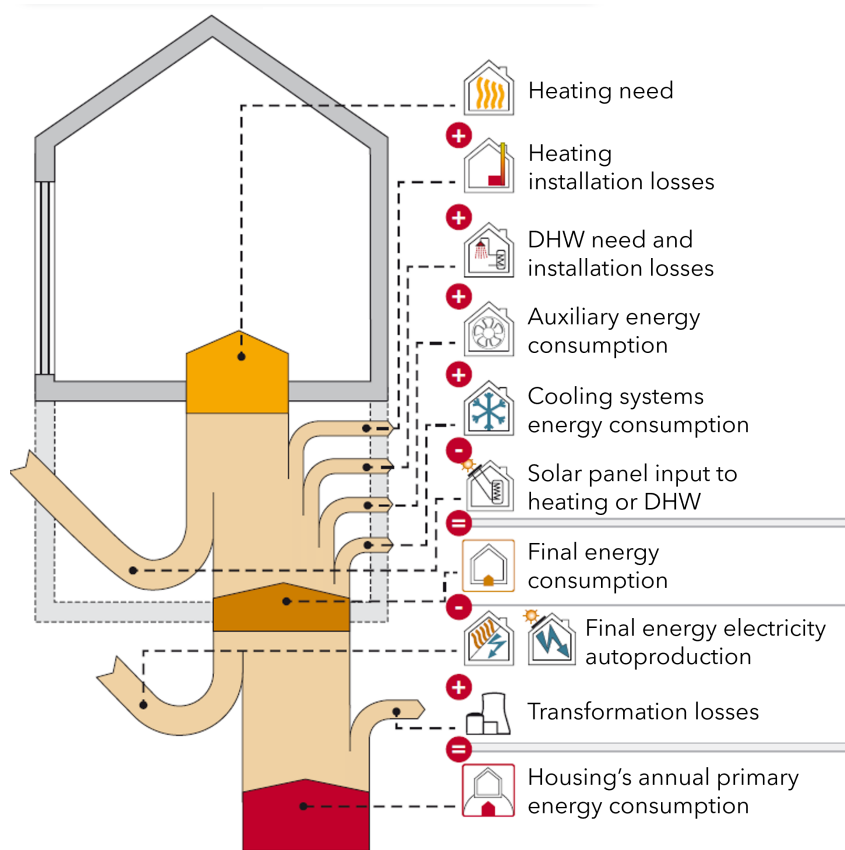


Figure 2.16: Schematic of BEP calculation method for housing primary energy consumption. From [53], translated to english

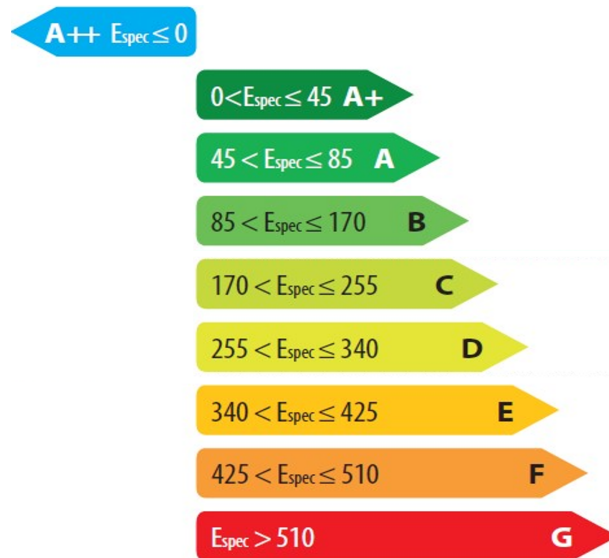


Figure 2.17: 9 categories of the BEP certification [53], values in kWh/m²/year

- Not re-isolated: the value is taken as the average of the most numerous categories: **E**, **F** and **G**, which gives the **F** category.
- Re-isolated: [54] indicates that 80 % of heat losses (30% from the roof, 25% from walls, 15% from windows 10% from the ground) comes from bad isolation.

Assuming an efficacy of reducing those losses by half in case of new isolation, this gives a 40% reduction (equivalent to BEP **D**).

- Younger than 40 years old: the majority of buildings either are in the category **B** or **C**
 - Good isolation: category **B**
 - Poor isolation: category **C**

Visually, the decision tree is presented in the figure 2.18

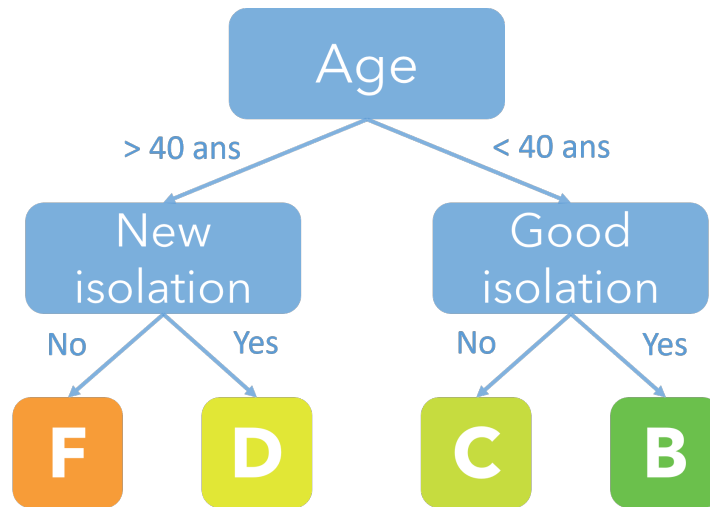


Figure 2.18: BEP choice following the age and isolation of the building

As said previously, the BEP gives a *total* primary energy consumption. To focus on the heating only, it is accounted that 73% of this energy is used for heating [45] after taking the average of each BEP category.

A.2 Construction coefficient Given the housing sample of [52], is chosen the average housing to be a three exterior facades house.

To form the construction coefficient, the type of building and the number of facades are used to manifest the difference from the average housing. For the former, in the case of an apartment, the model removes the heat loss from the roof, which accounts for 30% of the total losses [55] (assuming a confined apartment). For the latter, according to [55], about 40% of heat losses comes from windows and wall. So an increase of 10% of energy consumption per additional exterior facade is assumed, or a diminution if there are less than three facades.

A.3 preference coefficient In the BEP, the temperature inside the housing is supposed to be stable and at 18 °C [53] all the time. However, it is frequent to be able to module the temperature as a function of the time of the day. For that reason, the user can enter his preferences during two periods: day and night. From [56], the ideal temperature is said to be 19°C during the day and 16°C at night. If the day partition is made two-third day period and one-third night, the average is 18 °C in agreement with the BEP assumption.; Also, from the same source, each degree of difference from this ideal represents a 7% difference in heating need. This will be the basis of the preference factor: every degree difference is transmuted in a difference in heating need. To illustrate, if one like 21 degrees during the day and 15 during the night, it makes a $(2 \cdot \frac{2}{3} - 1 \cdot \frac{1}{3}) \cdot 7\% = 7\%$ increase.

With that, the model is complete. A schematic of the model is represented in the figure 2.19

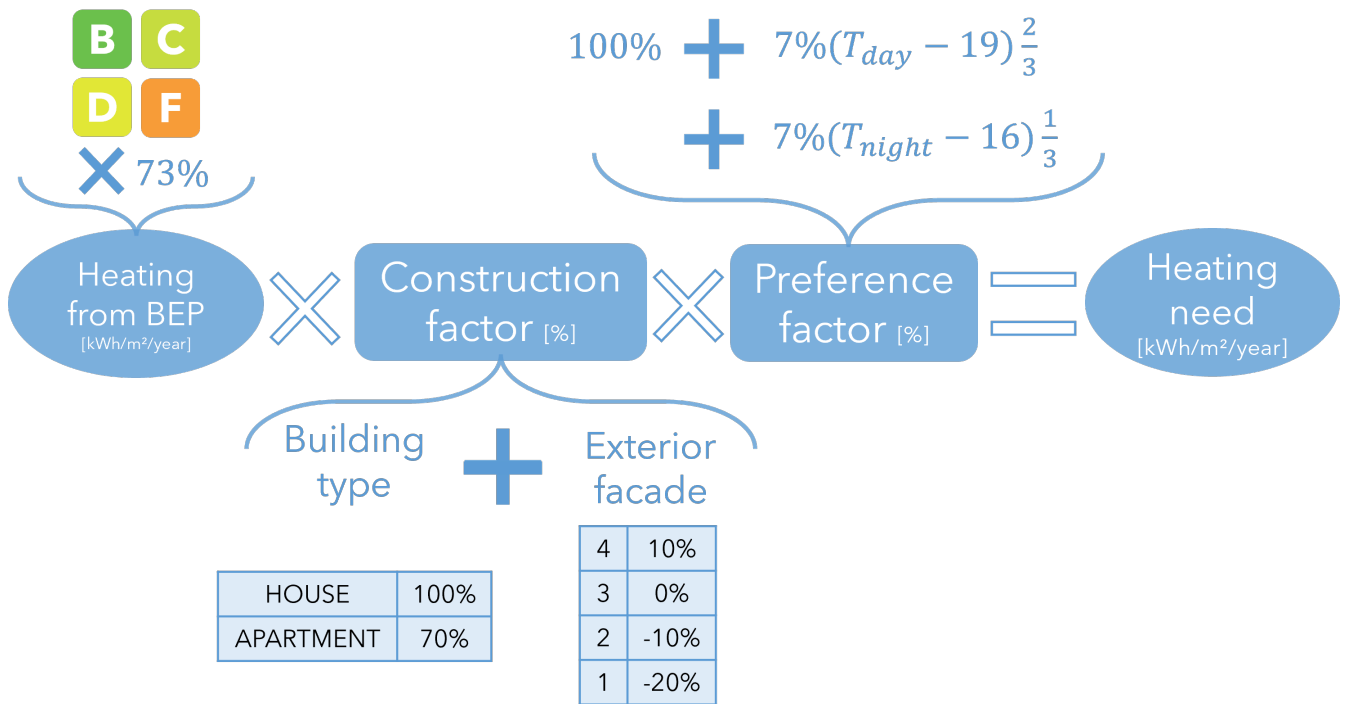


Figure 2.19: Heating need model

Pertinence and limitations As it is a great data source, the BEP system is not an exact picture of the current Belgian housing stock. Indeed, in 2016 there were 25% of certified housing in Wallonia; Furthermore, in [33] is explained that the results can be partly biased for two reasons. First, the BEP certificates are issued when a sale occurs, and the buyer often carries out renovation afterward. Second, BEP certifiers often use default values when there is no acceptable evidence. This is why the values used for the model might need to be updated when further data and larger samples of housings are

collected; Moreover, the dataset used is of Wallonia's real estate and does not account for Brussels' one, which can lead to additional uncertainty for Brussels' housings.

Finally, solar panels and cooling systems were not accounted for in the model due to their small share with flatshares; However, during the last decade, solar panels gained more and more success due to the rise of energy costs altogether with the BEP certification implications getting tougher by the year (lower indexation of rent, necessity of high BEP to sell housings), meaning that adding them into consideration could be a necessity in the years to come to be exhaustive (it is discussed in section 3.3).

The next step is to allocate those heating requirements to the heating station rightfully, and so energetic vectors, to convert it to equivalent carbon emissions.

B. Energetic vectors and heating station As the BEP gives the amount of primary energy used, it can be assumed that the result of the heating need in [kWh/year/m²] is directly coming from one of the four energy vectors mentioned earlier (electricity, gas, fuel oil or wood) according to the type of heater. Their EF are in table 2.12.

Table 2.12: Emission factor of energy vectors per kWh. All data comes from [19] ADEME.

Energy vectors	Electricity	Gas	Fuel oil	Wood
Emission factors [g_{CO_2e}/kWh]	220	240	350	16.3

Different heating systems are considered in the questionnaire: electric central heating, heat pump, gas central heating, oil central heating, and wood boiler. The "I don't know" option is considered as the major use in Belgium [45], so a gas central heating. As explained earlier, the questionnaire does not consider solar panels, but also coal and propane-butane for either the heating or the DHW because they all represent less than 2 % [45] of the energetic consumption in Belgium for DHW (2% propane-butane, and 0.03 % for coal) and less than 2 % also for the heating (1% for coal and 2% again for propane-butane).

However, precision must be added for electricity: between an electric boiler [57] and a heat pump, there is a factor three in efficiency [58] (regarding 55° water and water-air exchange heat-pump). Moreover, the BEP applies a 2.5 factor to convert electricity into primary energy [59]. As the EF is used directly on the vectors, in the case of electricity use, the result is divided by 2.5 and again by three if the user uses a heat pump.

Concerning the auxiliary heater, taken as an electric heater, the consumption of reference is the one of an electric radiator [60] with a power of 1500 W and used during five months (between the end of autumn and the beginning of spring) 6 hours per week. It gives an energy consumption of 200 kWh, which will be added to the total electricity of the housing.

The emissions value is computed by using the EF in the table 2.12, with the addition of 8% accounting for the electricity line losses [61]. Its influence is shared between the inhabitants of the housing.

To finish incorporating the energy requirement, the model for flatshare and household combination must be specified.

C. Flatshare and household combination

To ensure the computation accounts for the proper emissions in the user's global balance, the model should factor in the year distribution in the two housing. Indeed, if the user resides in his flatshare three quarters of the year, he should not *pay* for a whole year share of his household.

This addition only impacts the category **1** and **2** users, given the category **3** users being considered only living in his flatshare. The handling of the two housing differ from each other:

For the household, the idea is to add to the heating requirement the *proportion* computed in 2.4.3.1. If a student resides 30% of the year in his household, his balance should account for 30% of the heating requirement. It must be pointed out that, for this model to work, the assumption that the heating requirement is apportioned equally during the year is made since the proportion computed in 2.4.3.1 is done by asking about the housing habits during exams periods, courses and vacations, and not a season per season which would be too elaborated.

For the flatshare, the situation is different. Like second-home owners, students are also responsible for the vacancy of their flatshare. To this end, **D-habit-heating-out** in the second question regards three behaviors of heating management during *off-peak* periods: to stop the heating, to not change anything, and to decrease it. For the first two, the factor *Proportion* is taken from 2.4.3.1 or 1, respectively. However, for the last one, more hypotheses must be made:

To model the decrease compared to someone not changing anything, the temperature preference is assumed to be set at 15 °C when the flatshare is unoccupied. To factor it, the decrease reduces the proportion of time spent in the household in consumption, i.e., the diminution to 15 degrees from the user's habits would give. In concrete terms, this can be written as in 2.2:

$$\begin{aligned} \text{Proportion}_d = \text{Proportion} + (1 - \text{Proportion}) \cdot (1 + (2 \cdot (15 - \mathbf{X-kot-temp-day})/3 \\ + (15 - \mathbf{X-kot-temp-night})/3) \cdot 0.07) \quad (2.2) \end{aligned}$$

For example, if a user stays one-third of the year in his flatshare and whose heating habits are 20 degrees during the day and 18 during the night, this would give 2.3

$$\text{Proportion}_d = 0.33 + 0.66 \cdot (1 + (2 \cdot (15 - 20)/3 + (15 - 18)/3) \cdot 0.07) = 0.33 + 0.66 \cdot 0.7 = 0.79 \quad (2.3)$$

In this example, the 0.7 factor means that decreasing the flatshare heating amounts to saving 30 % of the usual heating during the time spent at the household.

2.4.3.5 Electricity and water

Given the small number of questions these sections contain, electricity and water are joined together in the questionnaire. However, their model is detailed separately for convenience.

For the electricity, similarly to the housing area, is asked only an estimation. The models again differ for flatshares and households.

For the water part, the user may have to enter a heating system depending on his category and hygiene habits.

The sub-module display is in figure 2.20, conditions in figure 2.21 and variables description in table 2.13

The screenshot shows a questionnaire form with a light blue background. The text is in French. The first line asks to qualify electricity consumption (excluding heating) as 'normal' (between 2000 and 3000 kWh). The second line asks for the average number of showers per week, with options for short (<4min), long (>4min), and baths. The third line asks for the heating system used in the house.

Je qualifierais la consommation électrique (hors chauffage) de la maison comme normale (entre 2000 et 3000 kWh) .

Lorsque je suis à la maison, je prends en moyenne par semaine (complète) 4 douches courtes (<4min), 2 douches longues (>4min) et 1 grands bains.

L'eau de La maison est chauffée par une pompe à chaleur

Figure 2.20: Electricity and water formulation

A. Electricity

As seen previously, electricity can be used for all energy-consuming sources of the housing (see table 2.7). This part focuses only on the appliances and devices consumption. This is why is indicated "excluding heating" in the questions *Electricity*.

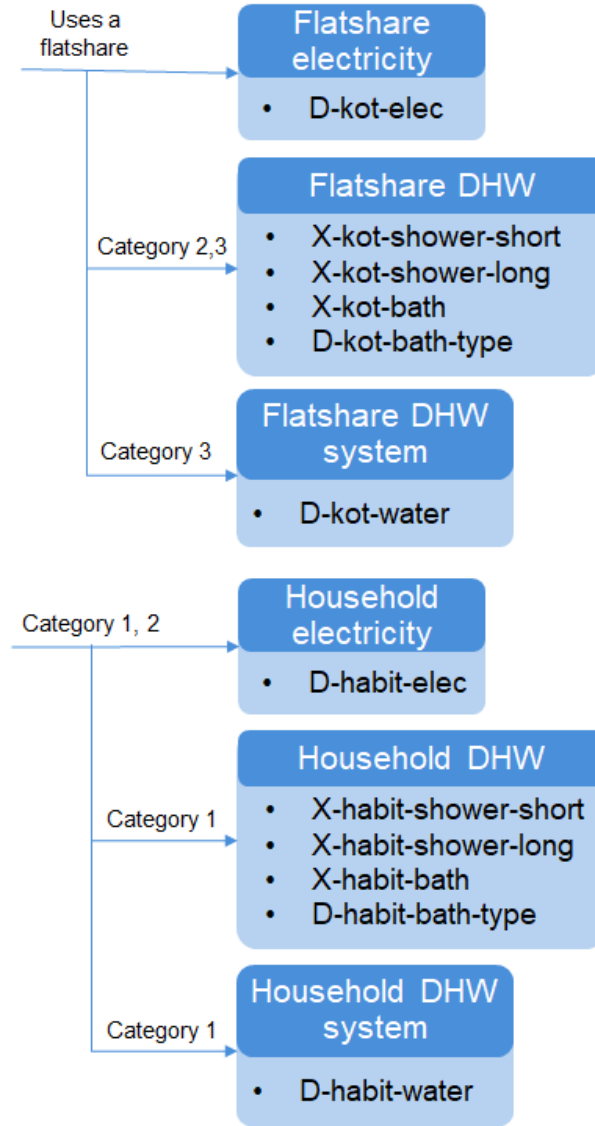


Figure 2.21: Electricity and water conditions

Between household and flatshare, only the estimations change. They are distinct because household are assumed to be more equipped in term of appliances and electrical devices than flatshare. To model this difference, is listed a series of common devices and appliances in table 2.14⁷ to compute the total electric need; Also, to differentiate the choices of **D-habit-elec** and **D-kot-elec** is applied the same factor as the area, i.e 0.75 for *small* and 1.25 for *large*.

Once the consumption is determined, an 8% addition for the electricity line losses [61] is applied and the total is converted into emissions thanks to the EF and shared across the inhabitants.

It is finally multiplied by the *Proportion* factor to share the consumption between the 2

⁷To be noted that the assumption of electrical cooking from 2.4.3.2 is represented here. Has been chosen induction plate for the household [62] because they are the most common, and glass-ceramic plate for the flatshare, because they are cheaper than induction.

Table 2.13: Electricity and water variables description

Variables name	Description
D-kot-elec	Flatshare electricity consumption (small, medium, large)
X-kot-shower-short	Number of short showers taken per week
X-kot-shower-long	Number of long showers taken per week
X-kot-bath	Number of baths taken per week
D-kot-bath-type	Type of bath taken (small, large)
D-kot-water	Flatshare DHW system (elec, heat pump, gas, fuel oil, wood)
D-habit-elec	Household electricity consumption (small, medium, large)
X-habit-shower-short	Number of short showers taken per week
X-habit-shower-long	Number of long showers taken per week
X-habit-bath	Number of baths taken per week
D-habit-bath-type	Type of bath taken (small, large)
D-habit-water	Household DHW system (elec, heat pump, gas, fuel oil, wood)

Table 2.14: Appliances time of use and electrical consumption. In italic appliances considered for the flatshare. (1) Combined refrigerator is a fridge with a freezer included. (2) Only for the flatshare. (3) Only for the household. From [63]

Appliance name	Operating time	Consumption [kWh]
<i>Combined refrigerator</i> ⁽¹⁾	<i>365 days/year</i>	<i>175</i>
Freezer	365 days/year	215
Dishwasher	5 cycles/week	225
<i>Micro-wave</i>	<i>1h30/week</i>	<i>60</i>
<i>Electrical oven</i>	<i>4h30/week</i>	<i>150</i>
<i>Glass-ceramic plate</i> ⁽²⁾	<i>2 plates/2x/day</i>	<i>260</i>
Induction plate ⁽³⁾	2 plates/2x/day	210
Plasma screen television	4 hours/day - 350 days/year	450
Washing machine	10 hours/week or 200 cycles/year	270
Dryer	100 cycles/year	200
<i>Vacuum cleaner</i>	<i>2 hours/week</i>	<i>115</i>
<i>Personal computer</i>	<i>8 hours/day</i>	<i>225</i>
Total		985 / 2295

housing. In fact, contrary to the heating, the majority of the flatshare electrical devices are active consumption (except for the fridge, which still consumes less if it is not open multiple times per day), so it makes sense to take only a share linked to the proportion

B. Water

The emissions of this section are exclusively focused on the heat required for the DWH used, as the emissions of network water and wastewater treatment are of two orders of magnitude less than the emissions for heating ($10^{-4}kg_{CO_2e}/l$ [19] vs $10^{-2}kg_{CO_2e}/l$, as will be seen below). With an average consumption of around 100 litres of water per day and per person in Belgium [64], accounting for the wastewater would give less than $10 kg_{CO_2e}/year/hab.$

Thus, the purpose of this section is to estimate the total volume of DHW used per year. With this, the theoretical heat required can be calculated. Depending on the user's housing category, this energy is linked to a heating station, and with an efficiency coefficient we retrieve kWh-energy-vectors, which can be transferred to CO_2e .

As observed in figure 2.21, the DHW consumption is summarized as the number of showers and baths taken per week, with the possibility to indicate the type of bath.

The hygiene habits are asked only once and are assumed constant throughout the year. The place corresponding to those habits is where the user spends the most time: for category **2** and **3** it is the flatshare, and for category **1** it is the household. The household hygiene habits are assumed equal to the flatshare's for the first category and inversely for the category **2**.

The number of showers, their length, the number of baths, and their type allow for estimating the volume of DHW used. The conversion factors are shown in table 2.15.

Table 2.15: DHW volume used for different showers and baths. (1) Taking a hot water flow of 15 l/ min for a shower [65], and 3 and 6 minutes for a short and a long shower, respectively. (2) Values from [66]

Type	Short shower ⁽¹⁾	Long shower ⁽¹⁾	Small bath ⁽²⁾	Large bath ⁽²⁾
Volume [l]	45	90	120	200

The next step is to transform this volume into the energy needed to heat it. Assuming a temperature gap from 15 to 55 degrees, with a constant specific heat $c_p = 4.18kJ/kgT$ and a density of $\rho = 1000kg/m^3$, we get the required energy E with the equation 2.4

$$E = c_p \cdot \rho \cdot \Delta T = 0.046kWh/l \quad (2.4)$$

Once the theoretical energy is computed, the water heating system's efficiency must be applied to get the primary energy consumed (see table 2.16). The station proposed in **D-kot-water** and **D-habit-water** are similar to the heating devices and asked only depending on categories.

For the electrical heaters, again, will be applied an 8% rise for the electricity line losses.

Finally, the water need is multiplied by the *proportion* to consider the share of the housing.

Table 2.16: Efficiency of the different heating systems. (1) Is taken a COP of 3, 55° water and water-air exchange [58]. (1) The wood-fired boiler efficiency can be highly variable according to the type of wood (logs, pellets, or chips), which is assumed to be a pellet wood-fired boiler.

Type of heaters	Efficiency [%]
Electric heating [57]	100
Heat pump ⁽¹⁾ [58]	300
Gas central heating [67]	90
Fuel-oil central heating [68]	90
Wood central heating ⁽²⁾ [69]	80

2.4.3.6 Meters

To let the opportunity for the user to correct the different energy vector estimations with his actual consumption, he can change the estimation of electricity, gas, and fuel oil.

As each quantity can vary on the zone of impact (e.g., the electricity can be only for appliances, but also for heating and DWH), is applied a correction factor to every post concerned, assuming that the change given the estimation made is equally shared between the posts. the factor is simply $meter_{value}/estimation$

The estimation contains a sum of every post the vectors works on. For example, is the user has a electric boiler for the DWH, the electricity estimation will be the electricity consumption 2.4.3.5 summed to the DWH energy need 2.4.3.5. For the DWH, the energy consumed is multiplied by the number of inhabitants, assuming that they share similar personal hygiene behaviors.

The questionnaire formulation and conditions are in figure 2.22 and 2.23, respectively.

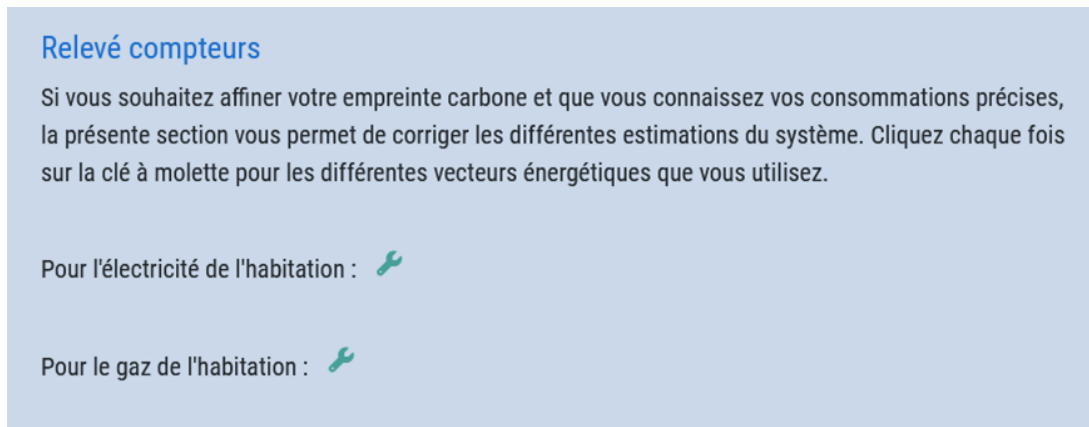


Figure 2.22: Meters formulation

To facilitate the completion, in the case of fuel-oil use, the consumption is converted to liters instead of kWh with its calorific power of 9.96 kWh/l [70]. As for the gas, it has been chosen to keep it into kWh as it is the norm used in the bills.

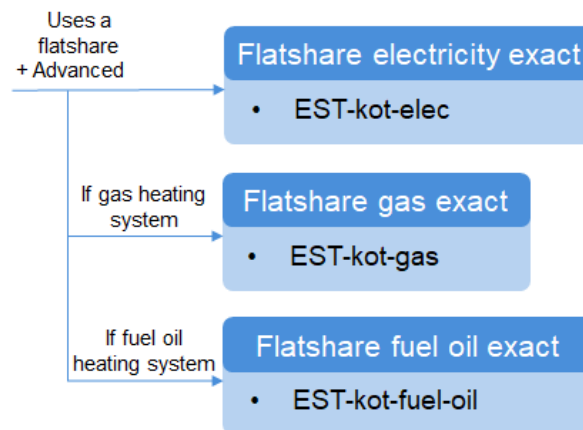


Figure 2.23: Meters conditions for flatshare, similar to the households

2.4.3.7 Waste

The final sub-module of housing deals with the cost of typical housings waste. Display in figure 2.24, conditions in table 2.25 and variable on table ??.

The first step is to account for all types and quantities of waste thrown each month. Then, they are converted to emissions with EF from [19]. As the EF is given per kg of waste, the quantity entered by the user is converted to mass thanks to volume and density assumptions.

Déchets

Lorsque je suis à la maison, je trie mes déchets

Chaque mois, nous jettons en moyenne 3 sacs d'ordures ménagères, 3 sacs PMC, 2 caisse de papier-carton, 1 caisses (12 bouteilles) de verres à recycler et environ 2 litres de déchets organiques (une poubelle composte +- = 20 litres) qui vont dans mon jardin (compost) .

Figure 2.24: Waste formulation

The user needs to first mention if he usually sorts them. If yes, different categories are considered: household waste, PMC (Plastic, Metal, Carton), paper and cardboard and glass. Quantity and disposal of organic waste are added following the category of the user. If he does not sort, everything is summarized as domestic waste.

The organic waste is added only for the category **3** for flatshare and for the category **1** for the household.

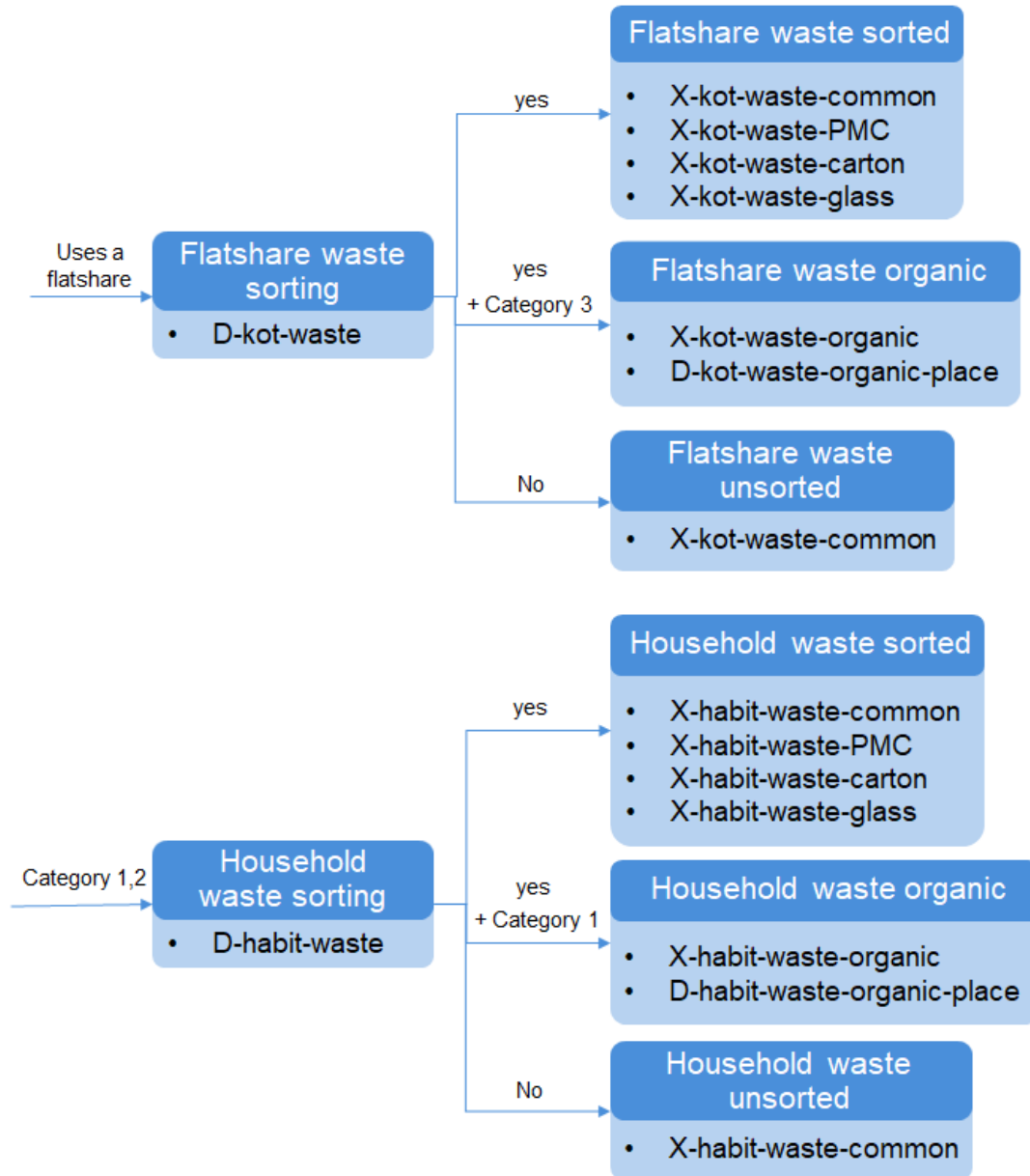


Figure 2.25: Waste conditions

To turn the quantity of bags, boxes, and the number of bottles into mass, the factors in table 2.18 are used. Afterward is applied the EFs and the total is divided by the number of inhabitants of each housing.

Only for the organic waste, three factors are used:

- w/ common waste: same factor as household waste ($0.345 \text{ kgCO}_2\text{e/ kg}$).
- Home compost: composting factor ($0.014 \text{ kgCO}_2\text{e/ kg}$).
- Dedicated container: industrial composting factor, $0.140 \text{ (kgCO}_2\text{e/ kg)}$.

Table 2.17: Waste variables description

Variables name	Description
D-kot-waste	if waste is sorted at flatshare (yes, no)
X-kot-waste-common	Nber of common waste bags per month
X-kot-waste-PMC	Nber of PMC bags per month
X-kot-waste-carton	Nber of carton boxes per month
X-kot-waste-glass	Nber of glass boxes per month
X-kot-waste-organic	Nber of organic waste litres per month
D-kot-waste-organic-place	Organic waste disposal (Home compost, dedicated container, w/ common waste)
D-habit-waste	if waste is sorted at household (yes, no)
X-habit-waste-common	Nber of common waste bags per month
X-habit-waste-PMC	Nber of PMC bags per month
X-habit-waste-carton	Nber of carton boxes per month
X-habit-waste-glass	Nber of glass boxes per month
X-habit-waste-organic	Nber of organic waste litres per month
D-habit-waste-organic-place	Organic waste disposal (Home compost, dedicated container, w/ common waste)

Table 2.18: Volume and density of each unity of waste. (1) From [71]. (2) From [72]. (3) *PMC* is assumed similar to compact plastic. (4) From [73]

Waste type	Volume	Density
Household waste	50 ⁽¹⁾ l	0.3 ⁽²⁾ kg/l
PMC	60 ⁽¹⁾ l	0.08 ^{(2),3} kg/l
Paper and cardboard	60 l	0.06 ⁽²⁾ kg/l
Glass	12 bottles	0.25 ⁽⁴⁾ kg/bottles
Organic waste	20 ⁽¹⁾ l	0.3 ⁽²⁾ kg/l

2.4.4 Mobility

The second module comprises every emission linked to the user's travel habits. That is on one side every direct emissions his trips cause like combustion gases, and on the other side every indirect emissions like fabrication costs of the means of transport he has used.

To compute mobility footprint, the global idea is to enumerate the different travels the user is likely to undertake, in terms of kilometres⁸ covered and means of transport employed which can be translated into emissions per distance. To achieve this, the module starts by categorizing the personal motored vehicles the user might use in the *Vehicles* sub-module,

⁸Only for long travels for weekends and vacations, the user can enter his trips in terms of time of travel. The reasons are exposed in the concerned section 2.4.4.4

for then listing the different mobility usage for each type of travel: first everything linked to the academic routine, then daily commute and finally the trips for week-ends or vacations.

2.4.4.1 Vehicles

The purpose of this first sub-module is to characterize the *private* vehicles (cars, motor-cycle and scooter) the user use for travelling, so that he may be able to choose them as a mean of transport in his different trips afterwards, and to account for their fabrication emissions in his footprint. Two pieces of information are looked for: the fuel type and consumption are needed, as well as the total construction emissions.

Models for both are explained here after the display of the questionnaire, conditions, and variables in figure 2.26, 2.27 and table 2.19 respectively.

Véhicules

J ai un permis (moto, voiture ou autre).

J ai mon véhicule personnel et j'ai 0 autres véhicules à ma disposition (= véhicule que je ne suis pas le seul à utiliser).

Mon véhicule personnel est une voiture essence et il a environ 8 ans. 

Figure 2.26: Vehicle formulation

Two types of vehicles are considered: *personal* and *shared*⁹. For each vehicle the user uses, is asked the type, the motorization and the estimated age of the car. That leads to a fuel consumption estimation the user can correct if needed.

The only difference between *personal* and *shared* is that for the second, the number of people driving the car is demanded.

A. Fuel consumption

Using the type and motorization of the vehicle, it is possible to estimate the mean fuel (or electricity) consumption per 100 kilometres, which in turn can be translated into equivalent carbon emissions per 100 km.

For simplification, the car's models are not specified (sedan, urban, SUV, etc.), and hydrogen is not taken into account, given its small market share [74]. Same for LPG (four

⁹The user can add up to 2 shared vehicles, but in this section is shown the questions for one only to avoid redundancy

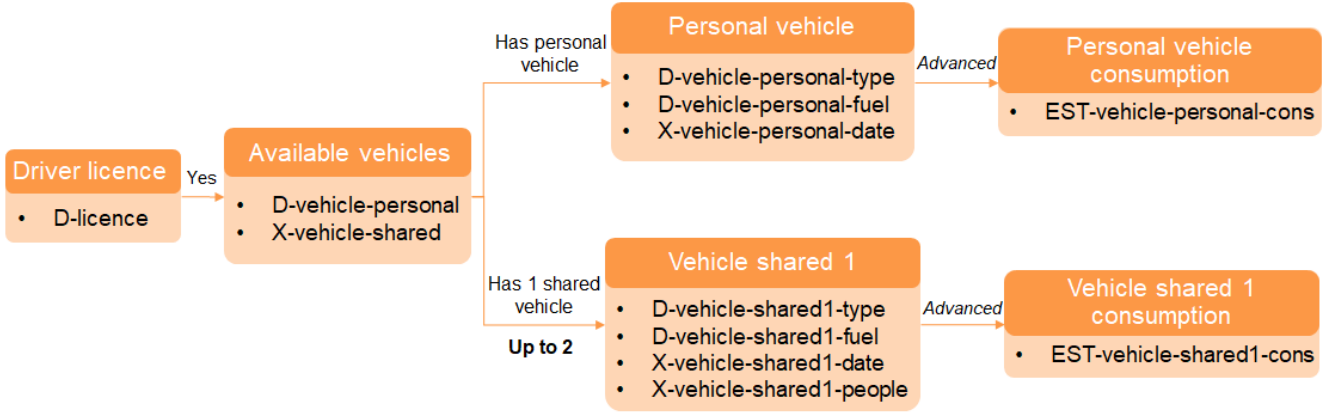


Figure 2.27: Vehicle conditions

Table 2.19: Vehicle variables and estimation description

Variables name	Description
D-license	If the user has a driving license (yes, no)
D-vehicule-personal	If the user has a personal vehicle (yes, no)
X-vehicle-shared	Number of shared vehicle available
D-vehicule-personal-type	Type of personal vehicle (car, moto, scooter)
D-vehicule-personal-fuel	Motorization type of personal vehicle (gasoline, diesel, hybrid, electric)
X-vehicule-personal-date	Age of the personal vehicle
EST-vehicle-personal-cons	Fuel consumption estimation of personal vehicle
D-vehicule-shared1-type	Type of first shared vehicle (car, moto, scooter)
D-vehicule-shared1-fuel	Motorization type of first shared vehicle (gasoline, diesel, hybrid, electric)
X-vehicule-shared1-date	Age of the first shared vehicle
X-vehicule-shared1-people	Number of people the vehicle first shared is shared with
EST-vehicle-shared1-cons	Fuel consumption estimation of first shared vehicle

time smaller than electric, and stagnating [75]) and CNG [76] cars. Also, two-wheels are considered only gasoline and electric engine, due to the absence of diesel engines in this market [77].

A special case is hybrid cars, because they can use both electricity and fuel to drive; Moreover, can be distinguished two types of hybrids:

1. *Non-chargeable* hybrid, which regroups Hybrid Electric Vehicle (HEV) and Micro-Hybrid (MHEV) are characterised by a relatively small electric autonomy (representing around 1-3 km [78]) and an electric-powered motor which aims to support the thermal engine, charged through the energy from braking or from the gas engine

itself. This method leads to a reduction of consumption compared to a full thermal model of 10 % for MHEV and 40 % for HEV [79].

2. *Chargeable* hybrid, also called Plug-in Hybrid (PHEV) allows driving dozens of kilometres in total electrical state (usually between 40 and 80 km [78], but some models with more than 100 km of autonomy [80]). It can reduce fuel consumption up to 75% in comparison to thermal cars [80], however, it highly depends on the driver's habits (charging regularly, driving slowly and mainly in urban areas, etc.)

To simplify the consumption to a unique estimation, the "hybrid" option is summarized to be an *non-chargeable* hybrid vehicle, as it represents more than 70 % of the hybrid market share in Belgium [81]; Furthermore, a gasoline thermal engine is assumed, from which the consumption will be chosen with respect to the gasoline car consumption with a reduction of 30% (slightly higher than the mean between the MHEV and HEV reduction because the latter is more present in the market). The different consumption can be seen in table 2.20.

Table 2.20: Consumption of the different types and motorization of vehicles considered. (1) From [82], taking the mean between 2010 and 2019. (2) From [83]. (3) From [84]. (4) From [85]

Motorization	Car	Motorcycle	Scooter
Gasoline $l/100km$	5.3 ⁽¹⁾	4.1 ⁽¹⁾	2.3 ⁽¹⁾
Diesel $l/100km$	4.5 ⁽¹⁾	-	-
Hybrid $l/100km$	3.71	-	-
Electrical $kWh/100km$	20 ⁽²⁾	7 ⁽³⁾	2.5 ⁽⁴⁾

Estimating the consumption instead of directly using an EF per km lets the opportunity for the user to correct the questionnaire's estimation, with **EST-vehicle-personal-cons/EST-vehicle-share1-cons**. The vehicle consumption is presented (in litres per 100 km for gasoline, diesel, and hybrid and kWh per 100 km for electric) in advanced mode in the questionnaire, where he can enter a corrected version.

Finally, the EF of the different fuels is applied to obtain a factor of kg_{CO_2e} per km, which will be used in the next sub-modules.

B. Vehicles construction

A still discussed question in carbon calculators is how to manage the CO_2e weight of a vehicle. So far, two approaches have been used in carbon footprints: separating the weight of the vehicle from the one of the fuel used or using a depreciation factor per km driven. Given that a vehicle's lifespan can be established in terms of duration or distance (e.g., on average, 10 years of lifespan or 150,000 km driven for a gasoline car [86]), both approaches can be defended.

However, the depreciation aspect remains a matter of debate: what type of depreciation should be chosen? Some opt for constant depreciation: if the vehicle lives 10 years on

average, divide the weight by 10, and each user *pays* for the weight of the vehicle according to the number of years they use it. Nevertheless, it means that there is no differentiation between those who buy second-hand vehicles (and therefore reuse a vehicle someone no longer wants with the constraints that this may entail) and those who renew their vehicle every year by buying new (contributing to the addition of new vehicles to the market).

In response to this, others advocate that the buyer is responsible for the entire weight; it's up to him to distribute it as best he can by keeping the vehicle as long as possible. But in this case, the pre-owned buyer is relieved of the entire weight, however young the car is and how long he keeps it.

Declining depreciation model The solution proposed here is an *in-between* solution: depreciation throughout the vehicle's lifetime, but on a declining scale to encourage reuse and to avoid over-consumption.

The degressivity $f(x)$ is chosen to be linear, dependent on the age of the car and must respect 2 constraints:

$$\int_0^{t_{life}} f(x)dx = 1 \qquad f(t_{life}) = 0$$

Where t_{life} is the vehicle's lifetime. The first equation means that the vehicle's entire weight must be depreciated over its lifetime. The second equation considers depreciation to be completed at the end of the vehicle's lifetime, in the same way as houses are considered fully depreciated after a certain date.

Taking a linear function of the type $f(x) = ax + b$, we obtain the following function, visible on figure 2.28:

$$f(x) = \frac{2}{t_{life}} \left(-\frac{x}{t_{life}} + 1 \right)$$

So, to determine the weight proportion to be allocated to the user, ask him how old the vehicle is. Indeed, as we're looking at the annual carbon footprint, the idea is to integrate the previous function between the two corresponding years (e.g., if the user indicates that the vehicle is three years old, it's between 3 and 4 years old) to deduce the degressivity coefficient $g(a, b)$ and multiply this result by the vehicle's weight (see fig 2.29). Below is the development of this system:

$$g(a, b) = \int_a^b f(x)dx = \frac{2(b-a)}{t_{life}} \left(1 - \frac{b+a}{2 \cdot t_{life}} \right)$$

Knowing that a and b are consecutive years, we have:

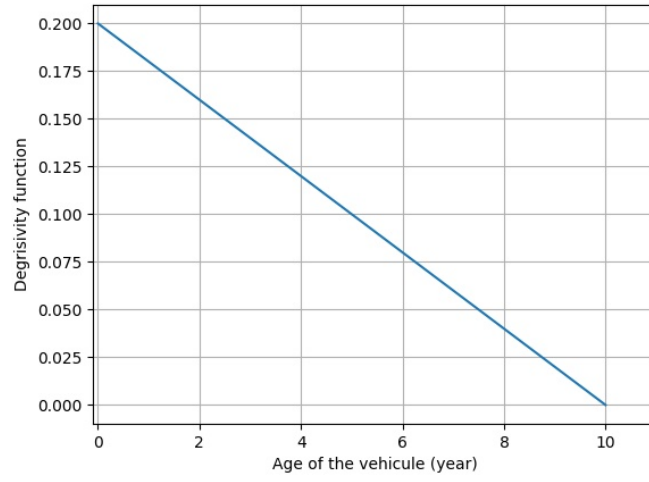


Figure 2.28: Degression function with vehicle lifetime $t_{life} = 10$ years

$$b - a = 1$$

$$b + a = 2a + 1$$

The equation can therefore be simplified:

$$g(a, b) = \frac{2(b - a)}{t_{life}} \left(1 - \frac{b + a}{2 \cdot t_{life}}\right) = g(a) = \frac{2}{t_{life}} \left(1 - \frac{2a + 1}{2 \cdot t_{life}}\right) \quad (2.5)$$

This formula then converts the user's data a (**X-vehicle-personal-date** or **X-vehicle-shared1-date**) into a proportion, setting it to 0 if the car's age is beyond its expected life.

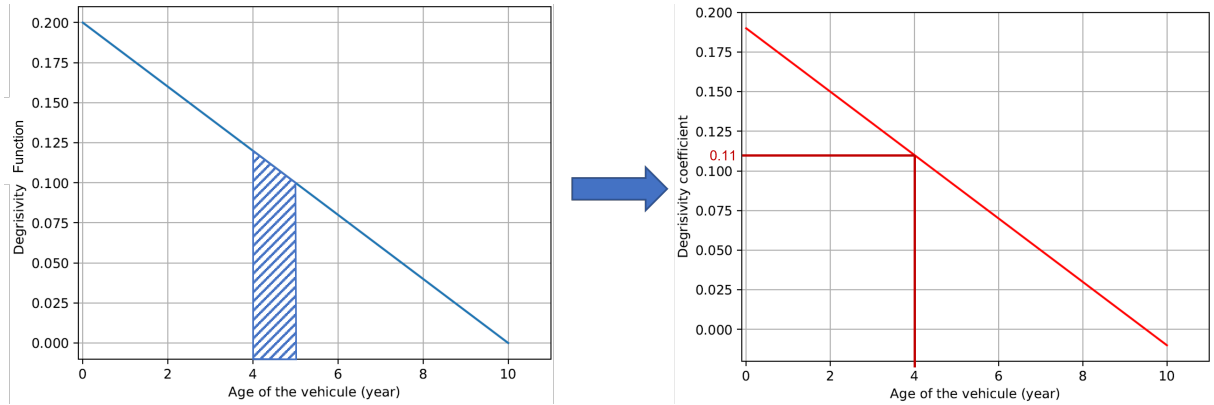


Figure 2.29: Function and coefficient of degressivity with vehicle lifetime $t_{life} = 10$ years

Then, the remaining step is only to multiply it by the vehicle EF, and apportioned between the different drivers if the vehicle is shared. From [31], is chosen the lifetime of 10 years for every vehicles.

Total emission per motorization type The last step is to find the total fabrication cost for each vehicle type. Two methods are employed depending on the available data: one for cars and one for two-wheels. For cars, data found in [83] gives the fabrication EF per kilometre. The total is computed by multiplying this FE with the life expectancy in kilometers for different type of motorization.

For two-wheels, the EF from [19] are in $kgCO_2e$ per kg. The total is calculated by multiplying it with the total mass of the different two-wheels.

On the first part, for the cars, the main difference to play here is the motorization: gasoline and diesel are of the same order of magnitude whereas electrical represents the double [83]. This is explained by the fact that batteries heavily impact the environment, accounting for 45 % of electrical vehicle emissions.

However, no data have been found for hybrid cars to characterize the fabrication cost. Knowing that 45 % of the emissions cost of an electric vehicle comes from the battery, and knowing that there is around three times less battery in terms of mass (about 300 kg in electric [87] and 100 kg for hybrid [81]), and accounting for the fact that a hybrid possesses two motors, its fabrication factors is estimated to be the cost of a thermal increased by 20 % of an electrical (15% for the battery and 5 % for the motor).

The resulting factors are shown in table 2.21

Table 2.21: Cars fabrication emissions for the different types of motorizations. (1) Assumption of same lifetime for both diesel and gasoline vehicles, taking the same assumption as the source of the EF [83]. (2) From [88]. (3) From [83]

Motorization	Lifetime <i>km</i>	Emission factor <i>gCO₂e/km</i>	Fabrication emissions <i>kgCO₂e/vehicle</i>
Thermal	150 000 ⁽¹⁾	40 ⁽³⁾	6 000
Electrical	160 000 ⁽²⁾	83.6 ⁽³⁾	13 376
Hybrid	150 000 ⁽¹⁾	56.7	8 505

On the second part, for the two-wheel vehicles, [19] gives a EF per weight of $4.5 kgCO_2e/kg$ for gasoline engines, and the supposed weight of the two types considered: 0.09 ton for a scooter, and 0.16 ton for a motorcycle¹⁰.

For the electric two-wheels, the assumption is made that the ratio of EF for thermal and electric is equivalent to the one for the cars. It gives $9.4 kgCO_2e/kg$, with a similar weight [89]. The fabrication weight are placed in table 2.22

2.4.4.2 Academic commute

For every routine journey, academic or otherwise, the procedure is to retrieve the mode of transportation, the length of kilometres of the trip, and its frequency to annualize it.

¹⁰Averaging motorcycle with cubic capacity smaller than 250 cc and larger 250 cc

Table 2.22: Two-wheels fabrication emissions for the different types of motorization. (1) From [19]

Type	Engine	Weight <i>kg</i>	Fabrication factor <i>kgCO_{2e}/kg</i>	Fabrication emissions <i>kgCO_{2e}/vehicle</i>
Motocycle	Gasoline ⁽¹⁾	160	4.5	720
Motocycle	Electric	160	9.4	1504
Scooter	Gasoline ⁽¹⁾	90	4.5	405
Scooter	Electric	90	9.4	846

With all those data, all travel can be converted into equivalent yearly carbon emissions.

This division by trips and not by means of transport was elaborated to accompany the user through the various journeys he is likely to undertake. Indeed, a more straightforward solution would have been to ask him how many kilometers he travels each week/month with every mode of transportation. However, this solution can be heavier for the user to enter, as he needs to recall and sum up every trip he does with each mode of transport. For that reason, a more *taken by the hand* solution was put in place; However, the difficulties are then to let the user enter all his trips, even those which are not in the main narrative (journey to go to school, to the flatshare, to hobbies, etc.), and all his modes (a trip can contain multiple means). The answer to those problems was first to let the user enter the weekly/ monthly trips he couldn't enter at the end of the *daily commute* section and second to summarize the journey to its main mean of transport (the reason why "*en majorité*" figures in every question concerning modes of transportation) while at the same time grouping every public transports into one factor (as explained in *Modes of transportation* here below), assuming that the users takes in large majority one of the modes proposed.

As it is the first section about travels, it begins by explaining the questionnaire and then exposes the models concerning the different modes of transportation and concerning the distance and frequency of trips.

In this sub-module are concentrated every travel linked to the user's tuition: round trips to the flatshare, the study location and any internships he may have. For this reason, the conditions and variables are numerous; However, the method stays equivalent for each type of travel, as explained hereafter.

The survey can be seen in figure 2.30 and the conditions and variables in 2.31 and 2.23.

The section begins with an *infomode* question to explicit what kind of distance is expected: every travel is considered one-way and doubled in the emissions computation. This was added to clear up any misunderstandings concerning the following different questions.

Trajets académiques



Pendant les cours, je vais en moyenne 4 fois par semaine à l'université et pendant le blocus/ les examens en moyenne 2 fois par semaine .

Je fais la majorité du trajet avec les transports en commun sur une distance de 25 km.

Ces 12 derniers mois je n ai pas eu au moins 1 stage.

Figure 2.30: Academic commute formulation

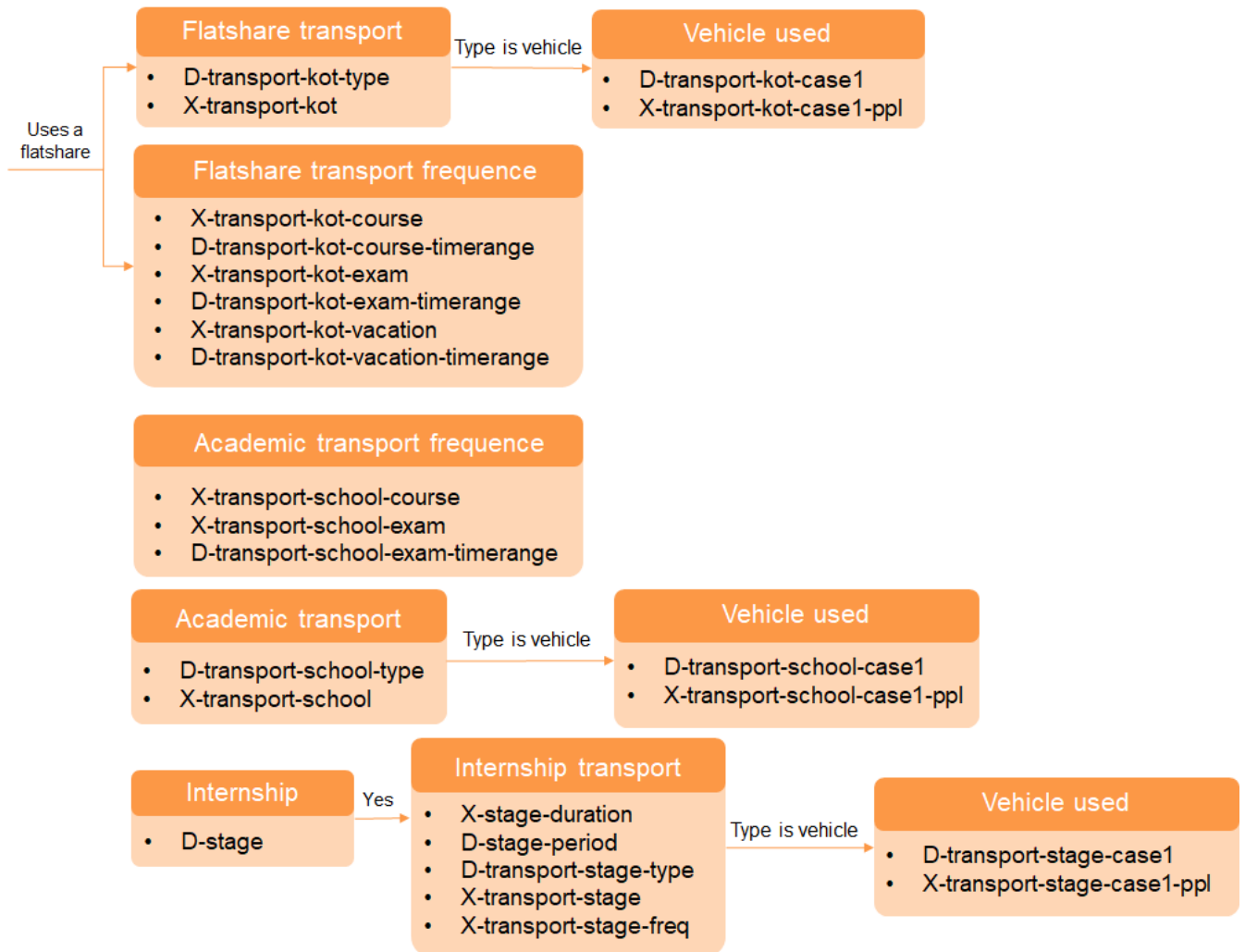


Figure 2.31: Academic commute conditions

Flatshare transport: Keeping the distribution of the year from 2.4.3.1, the subtlety here is to approximate correctly the total of trips: The student behavior may highly vary

Table 2.23: Academic commute variables and estimation description

Variables name	Description
D-transport-kot-type	Mean of transport used to go to flatshare (Vehicle, public transport, electric bike/scooter, bike, foot)
X-transport-kot	Distance in km to go to flatshare
D-transport-kot-case1	Type of vehicle used to go to flatshare (<i>Depend on the Vehicle sub-module answers</i>)
X-transport-kot-case1-ppl	Number of people in the vehicle
X-transport-kot-course	Number of travels to flatshare during courses
D-transport-kot-course-timerange	Timerange of travels (week, month)
X-transport-kot-exam	Number of travels to flatshare during exams
D-transport-kot-exam-timerange	Timerange of travels (week, month)
X-transport-kot-vacation	Number of travels to flatshare during vacation
D-transport-kot-vacation-timerange	Timerange of travels (week, month)
X-transport-school-course	Number of travels to campus during courses
X-transport-school-exam	Number of travels to campus during exams
D-transport-school-exam-timerange	Timerange of travels (week, month)
D-transport-school-type	Mean of transport used to go to campus (Vehicle, public transport, electric bike/scooter, bike, foot)
X-transport-school	Distance in km to go to campus
D-transport-school-case1	Type of vehicle used to go to campus (<i>Depend on the Vehicle sub-module answers</i>)
X-transport-school-case1-ppl	Number of people in the vehicle
D-stage	If user had an internship the last 12 months (yes, no)
X-stage-duration	Number of weeks of internship
D-stage-period	Academic period the internship took place (course, exam, vacation)
D-transport-stage-type	Mean of transport used to go to internship (Vehicle, public transport, electric bike/scooter, bike, foot)
X-transport-stage	Distance in km to go to internship
X-transport-stage-freq	Number of travels per week to go to internship
D-transport-school-case1	Type of vehicle used to go to internship (<i>Depend on the Vehicle sub-module answers</i>)
X-transport-school-case1-ppl	Number of people in the vehicle

between courses, exams and vacations. Also, an internship option is added, which need to be deducted from one of the three latter categories.

The question *Flatshare transport*: states for the two first info needed: the type of transportation, and the distance. The former is specified in the question *Vehicle used* in the case of *vehicle* choice in the sense of vehicle of personal use, together with the number of

people the trip is shared with. The second question try to recover the frequency of transportation for every part of the year, allowing changing the time range between weekly or monthly.

School commute: To not appear off-putting, the formulation slightly change compared to the flatshare questionnaire. First is asked the frequency of commutes for the courses and exams, and then the type and length of trips.

For internship: The addition here is the variable **D-stage-period**, which specifies the period of internship. This period can be either in one of the three categories from the proportion it needs to be deducted from the annualization to not take into account double trips (e.g. if the user had four weeks of internship during his usual course period, the transport to school will be taken onto 23 weeks instead of 27).

Now that is understood the questionnaire, the models needed to convert it to emissions will be exposed.

A. Mode of transportation

The objective is to give the user a list of choices sufficiently exhaustive so he can find his transportation, but still to be enough large to be able to summarize the transportation into one choice, as is asked only one type of transportation per travel to reduce the completion time (considering the number of travels asks in the different questions). The different means are: vehicle, public transport, electric bike or scooter, bike, and foot.

For the vehicles, another question is added to know which vehicle has been used (if the user has at least one vehicle at his disposal) and how many people take part in the trip to divide the trip's cost by the number of passengers.

For example, in the flatshare questionnaire, that information is in **D-transport-kot-case1** and in **X-transport-kot-case1-people**. The *case1* appellation comes from the fact that multiple cases are present depending on what vehicle the user might have at his disposal.

In the vehicle choice, the user can select one of the previously described vehicles and "Someone else's vehicle" if he is the driver or a passenger. In this case, as no information is known, the assumption is made that it is a gasoline car for the different commutes. This assumption is not ideal since gasoline cars represent about 50% of the automobile fleet in Wallonia, against about 40% for diesel[90], even if the diesel number is falling year after year due to more burdensome legislation against it.

Concerning public transport, it contains three types of mobility: tram and metro, train, and bus.

Even if the EFs (see table 2.24) differ between the different means of public transportation, for commute travel has been decided to mix them into a unique option, and this is because the questionnaire needs only one answer for the mean of transport to lighten it, and separating the three types would force the user to choose one only, even if his trip contains multiple means (e.g. in Brussels, cumulating metro/tram and bus).

However, to take into account that the metro and tram emissions are an order of magnitude smaller than the two others in terms of emissions and also the fact that metro and tram are the less used public transport (mainly because of their absence in the majority of Wallonia cities) in term of numbers of displacement, the mean factor chosen is a pondered geometric mean (see equation 2.6). The weights are in table 2.24

$$EF_{public}^- = \exp \left(\frac{\sum_{i=1}^3 w_i \ln x_i}{\sum_{i=1}^3 w_i} \right) = 39.15 g_{CO_2e}/km/passenger \quad (2.6)$$

Table 2.24: Weight for pondered geometric mean and EFs for public transportation. (1) Weight is the modal share of all transport mean in Belgium in numbers of displacement, from [91]. (2) Assuming diesel engine.

Type	Weight ⁽¹⁾	Emission factor
	—	$g_{CO_2e}/km/passanger$
Metro and tram	2.5	5.03
Train	4.2	48.4
bus	4	114 ⁽²⁾

Concerning soft mobility, there are two categories: electric and non-electric.

For the former, electric bike and scooter¹¹, can be retrieved from [31] the model for environmental impact on those two two-wheels. However, it was made for France, which has electricity five times cleaner than in Belgium (52 g_{CO_2e}/kWh VS 220 g_{CO_2e}/kWh). To translate this model, the utilization part corresponding to the different charges is multiplied by four. This gives 17.2 g_{CO_2e}/km for the bike and 27.8 g_{CO_2e}/km for the electric scooter (higher because it is assumed a smaller lifetime, 4 VS 12, and a more minor use per year). The final value considered is the mean between the two, so 22.5 g_{CO_2e}/km .

The latter, bike and foot, are considered as completely clean, so no emissions are added.

B. Distance and frequency

As explained in the *infomode* at the beginning of the sub-module, every distance entered for routine trips is considered as the one-way distance, meaning that every variable is doubled for the kilometres travelled.

¹¹The electric scooter (in french *trottinette électrique*) considered here are different from the scooter with fuel engine explained in the last section

The frequency method can slightly vary between the questions, but the principle stays the same: have an annualised behavior to get the total of kilometres wandered.

For the academic commutes, is followed the year partition seen in the housing section 2.4.3.1. With the flatshare, the behavior is asked during the three periods: exam, vacation and courses. For the school commutes, only exams and courses are regarded. The nuance here is that, if the user had an internship, he needs to declare during which period he had to deduct it from the school travels if it was during courses or exams.

2.4.4.3 Daily commute

The daily commute contains routine travels the user might have that are not academic related like hobbies, groceries, medical appointments, family reunions, etc. All those reasons to move from one place to another. However, being exhaustive onto all those trips is impossible as there are too many different profiles not to lose sight of the time of completion.

Trying to summarize it, at first is asked about hobbies or activities the user might regularly have (musical, sportive, cultural, or other activity). The questionnaire allows up to four hobbies to be detailed.

After, all the remaining trips need to be summarized into the two *daily travel* variables that aim to fill out the rest of the user transportation. Contrarily to all the other trips, here the user need to enter the total distance, and not just the one-way travel. This is why is indicated "*au total*" in the *Daily transport frequency* question.

Again, display, conditions and description are available on 2.32, 2.33 and 2.25.

Autres trajets

En dehors de mes études, je pratique **1** activités (sportives, culturelles, artistiques, ...) qui nécessitent des trajets.

> Je pratique une activité **artistique** **2** fois par **semaine** . Je fais la majorité du trajet avec **mon vélo/ ma trottinette électrique** sur une distance de **10** km.

Pour les autres trajets du quotidien (courses, job étudiant, ...), j'ai environ **15** km de trajet par semaine avec **un véhicule** (et **on est habituellement 2 personnes** dedans), et environ **20** km de trajet par semaine avec **-----**

Figure 2.32: Daily commute formulation

The questionnaire¹² and the different variables mentioned aim for the same type of infor-

¹²is displayed only one hobby, to avoid redundancy

mation as before: mean, distance and frequency. Only here, the travels are asked always on a weekly basis. For the daily travels, two variables are stated to allow the user to enter two means of transportation for the rest of their travels.

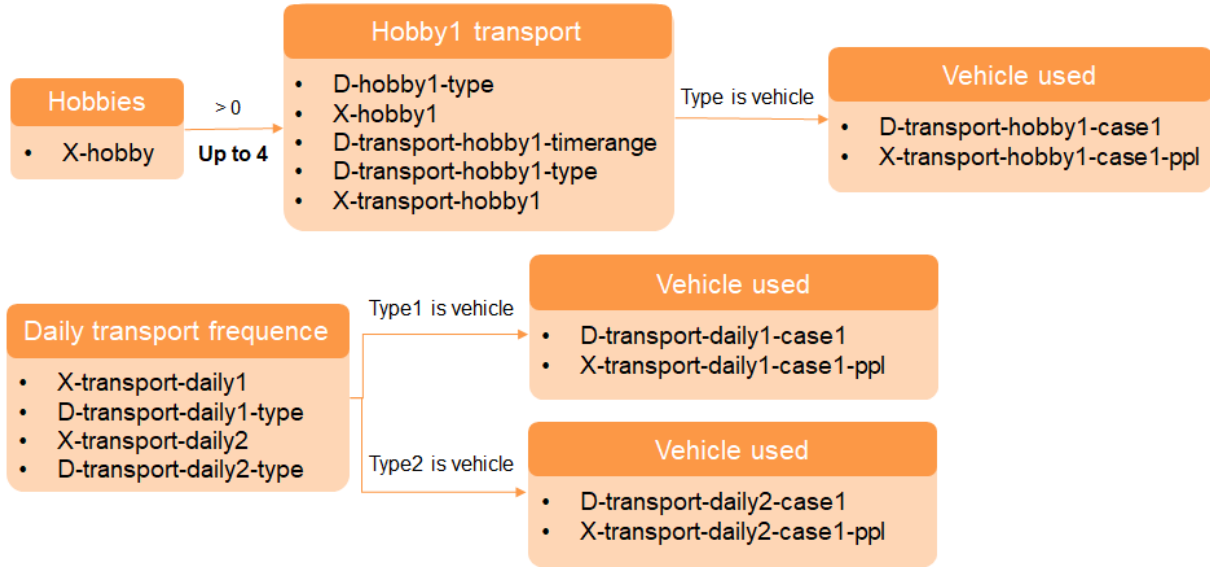


Figure 2.33: Daily commute conditions

2.4.4.4 Vacations

The Vacations section is the last of the mobility module. It takes in all Weekend trips as well as longer vacations. The principle is similar to the previous sections, looking for the distance and means of transport.

Yet, the method is a little different from before: the means proposed change, since long travel means need to be added, and the user get an alternative way to describe distances, the time of travel.

First, the formulation and conditions are exposed (in figure 2.34, 2.35 and in table 2.26), followed by the addition of new means of transport and the model of measuring distance with time values.

The question *Weekend and vacation* determine the number of detailed weekend and vacation the user need to fill in. He can enter up to four Weekends and three vacations detailed¹³.

¹³Again, only one weekend and one vacation are displayed to avoid redundancy

Table 2.25: Daily commute variables and estimation description

Variables name	Description
X-hobby	Number of hobbies (max 4 detailed)
D-hobby1-type	Type of first hobby (sport, art, music, other)
X-hobby1	Frequency of first hobby per timerange
D-transport-hobby1-timerange	Timerange of travels to first hobby (week, month)
D-transport-hobby1-type	Mean of transport used to go to first hobby (Vehicle, public transport, electric bike/scooter, bike, foot)
X-transport-hobby1	Distance in km to go to first hobby
D-transport-hobby1-case1	Type of vehicle used to go to first hobby (<i>Depend on the Vehicle sub-module answers</i>)
X-transport-hobby1-case1-ppl	Number of people in the vehicle
X-transport-daily1	Distance in km for daily commute 1
D-transport-daily1-type	Mean of transport used for daily commute 1 (Vehicle, public transport, electric bike/scooter, bike, foot)
X-transport-daily2	Distance in km for daily commute 2
D-transport-daily2-type	Mean of transport used for daily commute 2 (Vehicle, public transport, electric bike/scooter, bike, foot)
D-transport-daily1-case1	Type of vehicle used for daily commute 1 (<i>Depend on the Vehicle sub-module answers</i>)
X-transport-daily1-case1-ppl	Number of people in the vehicle
D-transport-daily2-case1	Type of vehicle used for daily commute 2 (<i>Depend on the Vehicle sub-module answers</i>)
X-transport-daily2-case1-ppl	Number of people in the vehicle

Vacances



Durant les 12 derniers mois, je suis parti **1** fois en Week-end et **1** fois en vacances (plus de 2 jours).

> Pour mon premier Week-end, j'ai fais la majorité du trajet avec **un train** pendant **3** heures (en comptant le temps de trajet, sans compter l'attente éventuelle dans les différentes plateformes).

> Pour mes premières vacances, j'ai fais la majorité du trajet avec **un avion** sur une distance de **4 000** km.

Figure 2.34: Vacations formulation

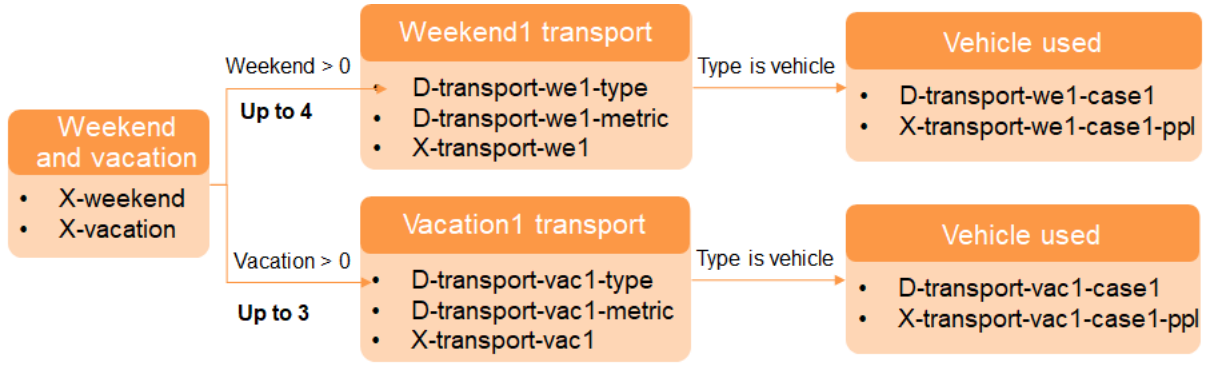


Figure 2.35: Vacations conditions

Table 2.26: vacations variables

Variables name	Description
X-weekend	Number of weekends off last 12 months (max 4 detailed)
X-vacation	Number of vacations last 12 months (max 3 detailed)
D-transport-we1-type	Mean of transport used to go to on first weekend (Vehicle, public transport, electric bike/scooter, bike, foot)
D-transport-we1-metric	Metric chosen to describe transport of first weekend (distance, time)
X-transport-we1	Distance in km or time in hours to go to first weekend
D-transport-we1-case1	Type of vehicle used to go to first weekend (<i>Depend on the Vehicle sub-module answers</i>)
X-transport-we1-case1-ppl	Number of people in the vehicle
D-transport-vac1-type	Mean of transport used to go to first vacation (Vehicle, public transport, electric bike/scooter, bike, foot)
D-transport-vac1-metric	Metric chosen to describe transport of first vacation (distance, time)
X-transport-vac1	Distance in km or time in hours to go to first vacation
D-transport-vac1-case1	Type of vehicle used to go to first vacation (<i>Depend on the Vehicle sub-module answers</i>)
X-transport-vac1-case1-ppl	Number of people in the vehicle

A. Means of transportation

The obvious addition is the possibility to take a plane but also will be added long-distance train (high-speed trains). The questionnaire must differentiate the latter from public transport to be coherent. So, regarding that tram and metro are not common transport for long travel, common (regional and intercity) train and bus are no longer joined.

For the planes, the EF differs considering the type of trips. They have been divided into three: short, medium, and long-haul. The specifications can be seen in table 2.27.

The list **X-transport-we1-type** and **X-transport-vac1-type** are then: a vehicle, a bus, a plane, an HST, a train, my bike, my foot. The user does not have the choice of the type of plane: it is deducted from the distance entered just after.

Table 2.27: Type of plane travels with EF. (1) EF from [31], with drag

Type of plane travel	Distance <i>km</i>	Emission factor ⁽¹⁾ <i>g_{CO₂e}/km/passanger</i>
Short-haul	<1000	258
Medium-haul	1000-3500	187
Long-haul	>3500	152

B. Distance with time

At weekends and even more during vacations, long-distance travels are expected, here defined as trips of more than 100 km. Even though they represent a small share of trips in number, they cause a high share of emissions: in Germany, they account for more than 60% of mobility emissions while for 2% of the total number of travels [92]. Unsurprisingly, they encompass up to 40% of the total distance traveled [93].

As it can represent more than half of the user mobility emissions, the question must be carefully chosen to help him enter the correct information, as some users can have difficulties estimating the correct distance the more significant it gets with a tendency to underestimate it, whether seeing the trip on a map [94] or reporting it as long-distance trip [95]. Those uncertainties were not accounted for in the previous sections, as the travel's length is supposed to be limited. However, estimating a plane trip to New York to be 3000 km instead of 6000 km can lead to miscalculating the emissions emitted.

For those reasons, the user can choose to describe the length of his trip in distance or time with **D-transport-we1-metric/D-transport-vac1-metric**: "*sur une distance de XXX km*", "*pendant XXX heures (en comptant le temps de trajet, sans compter l'attente éventuelle dans les différentes plateformes)*".

To make it work is needed a conversion factor to estimate the distance with the time spent traveling. In table 2.28 are regrouped all the mean assumed speeds for all the means of transportation. For planes and trains, average speeds are easily found, but it is more complicated for cars and buses as their average can vary depending on the trip. The assumption was taken that most of the travel is covered on highways.

Table 2.28: Average speed for different means of transport. (1) taken from Airfrance fleet [96], as an average between short, medium, and long haul plane speed (respectively around 800, 850, and 900 km/h). (2) "Common" states for trains that are not high-speed trains (regional, intercity, overnight, etc.). (3) Scooters are not mentioned as considered not a mean of transport for long trips.

Type of travel	Plane ⁽¹⁾	Train	Bus	Car	
Average speed <i>km/h</i>	850	Common ⁽²⁾ 100	High-speed 300	80	100

2.4.5 Food

The third module focuses on the food consumption and habits of the user. It first investigates the usual weekly menu separating meals and drinks, then the shopping routine and food waste management. The different EF used for this section does not come from

ADEME but from its alternative platform, which concentrates all food products: *Agry-balise* [97].

2.4.5.1 Eating

The user diet is separated into two categories: first the meals, in turn divided into breakfasts and dinner/supper; second the drinks split into hot drinks, soft and alcoholic beverages. They are joined in the sub-module, but for clarity, they are explained separately in this section, starting with the meals.

A. Meal

Getting the user's carbon footprint linked to his exact diet is impossible. That would mean getting the data about every type and quantity of food he has eaten in the past year, which is unfeasible. Therefore, his diet is summarized as a typical week of meals, three meals daily.

Five types of breakfasts and six types of meals are listed. The idea is to create a representative meal of each category, divide it into its different ingredients and then sum up the carbon emissions of each of them.

First, the questionnaire is displayed (figure 2.36, 2.37 and table 2.29) and explained, for then describing the model used.

First, the user diet is asked with **D-diet**. Depending on the answer, the list of meals differs. This way is on one side for the user to feel recognized in the questionnaire (more personal, less general), and on the other side to limit the useless questions appearing, saving reading time.

The estimation **EST-food-skip** is a *fixed* variable to ensure that the user does not enter more than 14 meals for the week.

The EF emissions chosen for the different meals (breakfast or lunch/dinner) are based on the work of *Nos gestes climats*, an accounting tool where they detail the different ingredients of *standard* meal [98], themselves based on the *base carbone* data. They created a typical meal for each category, separating them into different elements. Computation for every option is stated in the appendix C, and synthesis can be seen in table 2.34.

Alimentation

Concernant mon alimentation, j'ai un régime **végétarien (pas de viande ni de poisson)** .

Le matin, pour mon petit déjeuner, je mange principalement **des céréales** avec **du lait végétal** .

Sur les 14 repas du midi et du soir d'une semaine type : je mange

- > **4** repas végétalien (sans produits animaux).
- > **7** repas végétarien 'léger' (sans chair animale mais avec des oeufs, un peu de fromage, ...).
- > **3** repas végétarien 'moyen', c'est à dire avec une quantité moyenne de produits animaliers (>150gr de fromages, >3 oeufs, ...).
- > Je saute en moyenne 0 repas par semaine.

Figure 2.36: Meal formulation

Table 2.29: Meal variables and estimation

Variables name	Description
D-diet	User diet (vegan, vegetarian, flexitarian, omnivore)
D-breakfast-food	Type of breakfast (continental, cereal, English, fruits, nothing)
D-breakfast-cereal	Type of side with the cereals (milk, plant milk, water, nothing)
X-vegan	Number of vegan meals per week
X-vege1	Number of soft vegetarian meals per week
X-vege2	Number of medium vegetarian meals per week
X-meat1	Number of white meat meals per week
X-vmeat2	Number of red meat meals per week
X-fish	Number of fish meals per week
EST-food-skip	Number of meals skipped per week

Breakfast Every description and EF of the five different types of breakfast are in table C.1. The fruits are linked to the vegan breakfast, and "nothing" causes no emissions to the user.

The cereal option is completed with **D-breakfast-cereal**. The plant-based milk is the mean of oak and soya; water and nothing in their turn summarize the breakfast to cereal only.

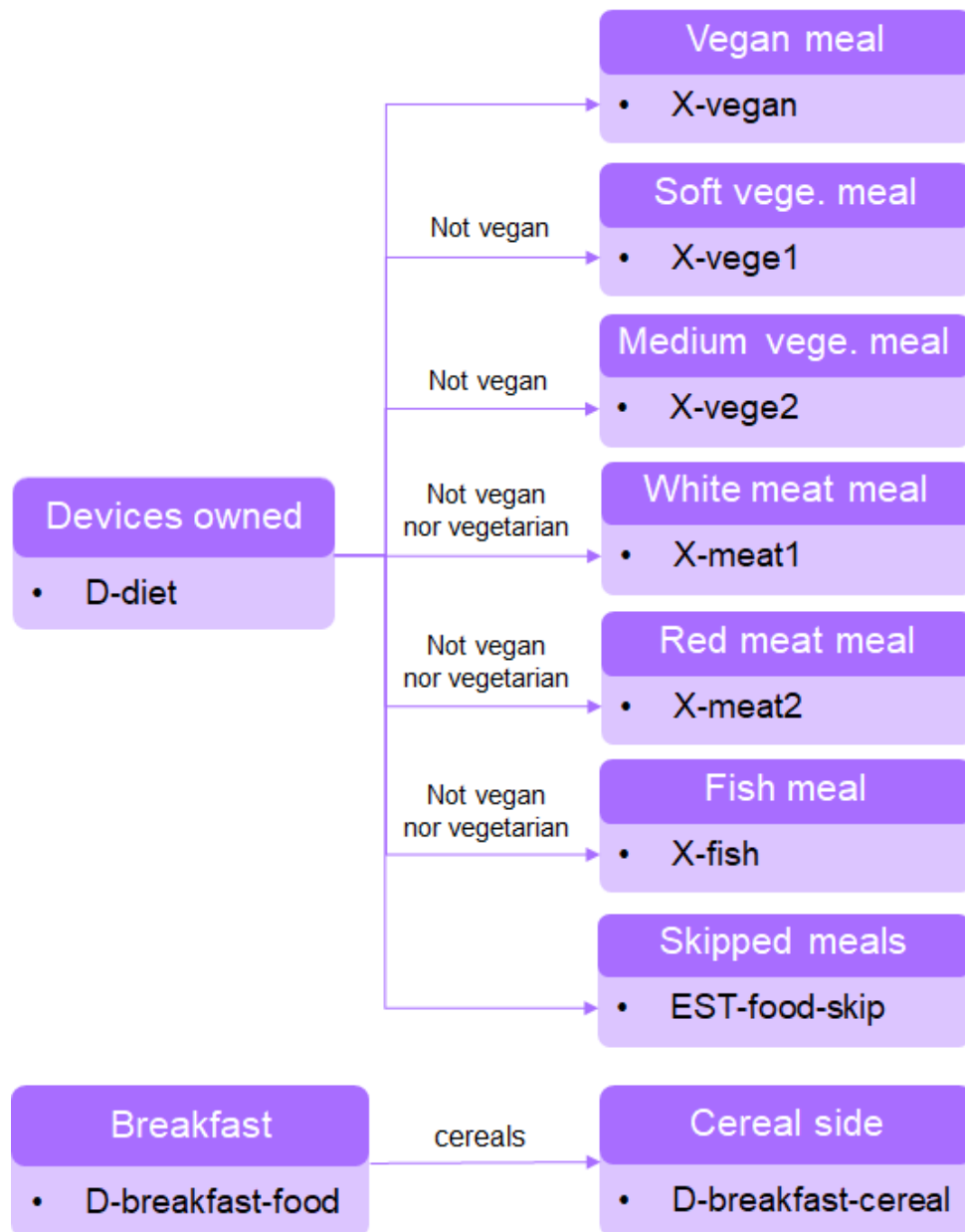


Figure 2.37: Meal conditions

Lunch and dinner As said before, they are six types of meals listed: vegan, light vegetarian, medium vegetarian (depending on the quantity of animal product), white meat, red meat, and fish. Those propositions differ slightly from the choices from [98]. The adaptations are to sum the two meals containing fish (C.7 and C.8) into one and the addition of a second choice for vegetarians.

The first modification is done by averaging the two fish meals, while the second is made by creating a new meal with the same method (see appendix C.4)

Two vegetarian meals are available because their emissions vary depending on the quantity of animal products. A high portion (as mentioned in the question, more than three eggs or 150 gr of cheese) can approach meals containing white meat. In fact, in *Nos gestes climats*,

the two are joined together ('containing a piece of chicken, pork, or cheese'). However, trying not to influence the user (if he sees meat or cheese while having a vegetarian diet, he might not select the option), the choice is made to separate them; Moreover, the student population is expected to contain a high share of vegetarian [99], and so offering more options can benefit precision for their balance.

B. Drink

Similarly to the meals, the weekly user habits are inspected. The questionnaire, conditions, and variables description are in figure 2.38, 2.39, and table 2.30. The drinks are divided into three categories (hot, soft, and alcoholic) to limit the number of questions asked.

Concernant les boissons

Niveau boisson chaudes, je bois environ par semaine **3** tasses (café(s), thé(s) ou chocolat(s) chaud(s)), avec une préférence pour **le café** .

Niveau soft, je bois environ **2** verres par semaine (jus, sodas, lait, eau en bouteille...), avec une préférence pour **les jus** .

Niveau alcool, je bois environ **2** verres par semaine (bières, vins, cocktail, alcools forts, ...), avec une préférence pour **rien, je prends de tout** .

Figure 2.38: Drink formulation

Hot drink

- X-drink-hot
- D-drink-hot-type

Soft drink

- X-drink-soft
- D-drink-soft-type

Alcoholic drink

- X-drink-alcool
- D-drink-alcool-type

Figure 2.39: Drink conditions

Table 2.30: Drink variables

Variables name	Description
X-drink-hot	Number of hot drinks per week
D-drink-hot-type	Type of favorite hot drink (coffee, tea, hot chocolate, nothing)
X-drink-soft	Number of soft drinks per week
D-drink-soft-type	Type of favorite soft drink (water in a bottle, juice, soda, milk, nothing)
X-drink-alcool	Number of alcoholic drinks per week
D-drink-alcool-type	Type of favorite alcoholic drink (Wine, beer, cocktail, nothing)

As EF and volume can differ for the different beverages (see table 2.31), the variables **D-drink-hot-type**, **D-drink-soft-type** and **D-drink-alcool-type** offer the opportunity for the user to specify his preference among the different drink, or selecting the option "nothing, I take everything", allocating an average EF per unit for the drinks. Indeed, even if coffee is consumed more than tea on average (with 4.6 kg/hab/year in Belgium vs less than 200 g of tea [100]), there are students excluding the former from their diet, and so assuming an average EF would create imprecision.

Table 2.31: Emission factors and unit volume of the drinks, and choice of the average value for modelization. (1) Water in bottles. (2) The factor comes from [97] and is assumed to have a density equal to the water (1 kg/l).

Type of Drink	Hot				Soft			Alcoholic		
	Coffee	Tea	Chocolate	Water ⁽¹⁾	Juice	Soda	Milk	Wine	Beer	Cocktail
EF per volume $g_{CO_2e}/cl^{(2)}$	60	52	148	27	100	40	1.67	123	112	90
Volume cl		20			25			12	25	25
EF per unit $g_{CO_2e}/unit$		173			209				218	

2.4.5.2 Groceries and wastes

Once the annual food and drink consumption is accounted for, this second sub-module seeks to characterize the shopping habits and the wastage management of the user. The section explains in this order the different models.

Here below the questionnaire, conditions (linked to the year proportion, see 2.4.3.1) and variables used (see 2.40, 2.41 and 2.32)

Courses

Je fais et choisis les courses **tout le temps** .

- > J'essaie d'acheter en vrac : **souvent, j'y fais attention**
- > J'essaie d'acheter local : **pas spécialement**
- > J'essaie d'acheter de saison : **Parfois**
- > J'achète en surgelé : **de temps en temps**

Concernant le gaspillage alimentaire: **J'essaie au plus possible de ne pas gaspiller**

Figure 2.40: Shopping formulation

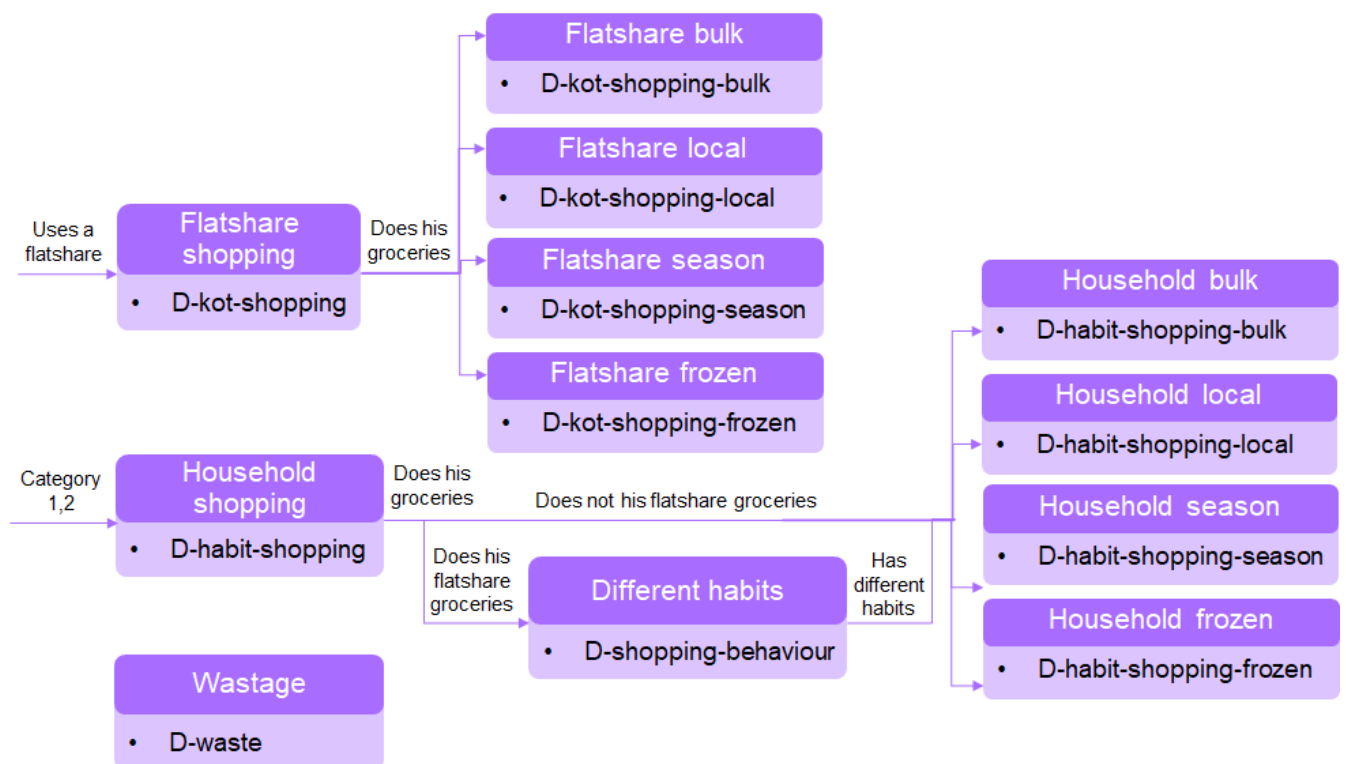


Figure 2.41: Shopping conditions

A. Grocery habits Four shopping behaviors are investigated: buying in bulk, locally, in-season, and frozen. The decision was made to factor into the user carbon assessment the shopping habits only if he chooses and shops himself. First to focus on the share of

Table 2.32: Shopping variables

Variables name	Description
D-kot-shopping	If the user does groceries at the flatshare (yes, no)
D-kot-shopping-bulk	Bulk shopping habits at flatshare (systematically, often, sometimes, rarely, never)
D-kot-shopping-local	Local shopping habits at flatshare (yes, not really)
D-kot-shopping-season	Seasonal shopping habits at flatshare (every time, often, sometimes, rarely, never)
D-kot-shopping-frozen	Frozen shopping habits at flatshare (majority, time to time, never)
D-habits-shopping	If the user does groceries at the household (yes, sometimes, no)
D-shopping-behavior	If the user has the same habits than at flatshare (yes, no)
D-habits-shopping-bulk	Bulk shopping habits at household (systematically, often, sometimes, rarely, never)
D-habits-shopping-local	Local shopping habits at household (yes, not really)
D-habits-shopping-season	Seasonal shopping habits at household (every time, often, sometimes, rarely, never)
D-habits-shopping-frozen	Frozen shopping habits (majority, time to time, never)
D-waste	Type of food wastage behavior (Never, less possible, it happens, don't care)

the impact of certain behaviors, which can be understood once living them. Second to be sure the user does not enter unknown information if he does not shop himself. The models for the different habits are first stated, and then the share between household and flatshare is explained.

Bulk More and more mass retail is increasing their bulk offer because the demand is rising as well, but also by obligation: The Climate and Resilience Act imposes that by 2030 20% of supermarket area need to be dedicated to bulk products [101]. At the same time, the bulk market keeps opening in Wallonia [102]. However, packaging wastes also increase year after year in Belgium [103], with a rise of 5 % between 2019 and 2020.

Yet, a large proportion of food can be bulk purchased: dry products (cereals, sugar, rice, etc.), fruit vegetables, fresh cut products (cheese, meat, cooked meat, etc.)[104]. And the apparent interest of this behavior is avoiding unnecessary waste.

From [105], it can be retrieved that in Wallonia, there are 17.1 kg per hab per year of plastic packaging (15.5 from gross domestic waste and 2.4 from PMC). The assumption is made that most plastic packaging comes from food products.

Contrarily to section *Waste* 2.4.3.7 where is accounted the disposal emissions, we consider here the fabrication emissions of packaging; Moreover, the focus is given to plastic packaging, as its EF is more significant than carton packaging (390 kg_{CO_2e} /tonne for carton vs 2383 kg_{CO_2e} /tonne for plastic), and also because it is harder to separate carton from food consumption from other posts of domestic life.

Then, starting from this mean, the questionnaire lets the user appreciate his consumption type and associate a change factor to it (see table 2.33).

Table 2.33: Conversion of textual answers into numerical factors for bulk shopping habits

Choices	Factor
Systematically	0
Often	0.5
Sometimes	1
Rarely	1.5
Never	2

If the factor is lower than one, the result will be a reduced user balance (as the food EF is based on *Agribalyse* EF, which contains packaging emissions). If the answer leads to factor 1, nothing is changed, and the two other options increase emissions.

Local The main difference regarded concerning local shopping is the emissions reduction from the travel part of the food. The model is again based on *Nos gestes climats* [25], which has chosen to implement it as follows:

For each typical meal and breakfast, every emission linked to the transport of each food is divided by two when bought locally. After recounting the emissions of every meal, it results in a *local* EF for each dish (listed in C). Then, is looked the proportional difference between the local and non-local meals, which determines the reduction ratio. The results can be seen in 2.34

Season Seasonal groceries are a difficult matter to model, as they cannot be summed up into one rule. For example, an apple is said to be of *new season* in March, but the offer in retail can be the past year’s apple leaving a few month’s trip in the cold chamber. Also, the off/in-season emission ratio can drastically change between two products (e.g, for a tomato in-season and out season there is a 3 factor, whereas for a strawberry less than 1.2, see in table 2.35); Moreover, the impact of eating in season can be lower than one can expect, as the seasonal proportion of food products is less than 10 % (considering the share in [106], accounting for tomato, apple and orange)

Again, the model is based on *Nos gestes climats* [25]. They computed the proportion of seasonal food to be 7.3 %. This percentage represents fruit and vegetables that can be bought seasonally, as well as other processed products such as fruit juices, soups, and

Table 2.34: Emission factor of dinner, lunch, and breakfast, basic and local. (1) averaged EF between different types of each category.

Meal	EF <i>g_{CO₂e}/meal</i>	EF local <i>g_{CO₂e}/meal</i>	Local reduction %
Lunch and dinner			
Vegan	785.18	690.12	12
Vegetarian soft	1115	1024.93	8
Vegetarian medium	1533	1445.09	6
White meat	2097.9	2033.9	3
Red meat	5510	5453	1
Fish ⁽¹⁾	1999	1888.9	5.5
Breakfast			
Continental	289.1	259.9	10
Cereal and milk ⁽¹⁾	319	298.9	7
English	1124	1103.16	2
Vegan	419.4	369.7	12

compotes, which can be purchased with knowledge of the production date of the product.

Then, is applied to this proportion, the ratio 2.26 computed in table 2.35. Therefore, The total seasonal habit effect on emissions is the difference between the original food emissions estimation and this reduction. This value is subtracted from the total computed in the last section.

Table 2.35: Computation of season ratio based on data from [97].

Name	EF <i>kg_{CO₂e}/kg</i>	Ratio <i>off/in season</i>
Tomato, in season, raw	0,58	
Tomato, off-season, raw	1,96	3,38
Strawberry, in-season, raw	0,48	
Strawberry, off-season, raw	0,55	1,15
Average		2,26

But, to avoid binary behavior, the user can choose between several descriptions, each with a factor multiplied by the previous value (see table 2.36).

Naturally, this model is incomplete. Partly because the ratio is computed only on two ingredients, but also because ideally, the difference off-season/in-season should be made similarly to the *local* difference, i.e., on every meal separately.

However, it still gives an approximation to help the user understand the effect of seasonal food purchases.

Table 2.36: Conversion of textual answers into numerical factors for seasonal shopping habits

Choices	Factor
All time	1
Often	0.75
Sometimes	0.5
Rarely	0.25
Never	0

Frozen Freezing and maintaining a meal frozen add inevitably a surplus in energy cost compared to the same non-frozen food. To model this rise, the emissions added are summarised by the electricity cost of keeping food at low temperatures.

The first step is to look for the extreme case: a user who freezes all his food, i.e., around 500 kg per year [106].

Taking a freezer of 1 kWh/l/year [107] (class A+ freezer), a period of six months of freezing before buying (average between vegetable and fruits, and meat [108]), and an average density of 1kg/l, this gives:

$$500l \cdot 0.5 \frac{kWh}{l \cdot year} \cdot 0.220 \frac{kg_{CO2e}}{kWh} = 64.25 kg_{CO2e}$$

This value is modulated based on the user's answer. He has the choice between three options associated with a factor for the value above (see table 2.37).

Table 2.37: Conversion of textual answers into numerical factors for frozen shopping habits

Choices	Factor
Majority	1
Time to time	0.5
Never, the less possible	0

Flatshare and household Again, the necessity of differentiating the household from the flatshare appears. Is used the system of category explained in 2.4.3.1.

For users with no flatshare, of from category **3**, only one list of shopping habits can be displayed (if they answer that they're doing groceries).

However, the users from category **1** and **2** might have different shopping habits between the flatshare and household (typically, a student who manages his groceries in the flatshare, but at home, his parents take care of it).

In that case, the user gets the opportunity to enter two types of habits: first with **D-shopping-kot**, he can enter his flatshare habits. Second, for the household with **D-shopping**. To avoid repetition, the user who has the same habits can enter it with

D-shopping-behavior. To be noted that **D-shopping** is not binary like **D-shopping-kot**. This is to let the user see the impact of his habits even if he does not do the groceries every time at home.

Finally, to keep the idea of "responsible if free to choose", is applied to the two habits, the time proportion computed in 2.4.3.1.

B. Wastage

Household food wastage can have many forms: meal leftovers, dried bread, rotten vegetables, dairy product over expiration date, etc. About 15kg of food is wasted per person per year in Wallonia [109]. With an estimated consumption of 500 kilograms of food per year per person [106], it means that the loss represents around 3% of the total diet.

To model this, assuming a balanced share of wastage across different meals and drinks, an increase is applied to every eating post. However, this increase is not constant, as the user gets the opportunity to describe his wastage behavior in the last question of the module. Similarly to previous approximations, the factor applied is based on the average behavior expected (here, a 3% rise), and to distinguish the remoteness of other behaviors from the mean, is applied a factor arbitrarily chosen. Here below is the dropdown **D-waste** with the factors (see table 2.38).

Table 2.38: Conversion of textual answers into numerical factors and rise for food wastage

Choices	Factor w/ average wastage	Rise [%]
Never	0	0
The less possible	0.5	1.5
It happens	1	3
I don't care	2	6

2.4.6 Consumption

This is the last module accounting for emissions of the survey. As its name applies, it contains the part of the user's consumption unrelated to the food.

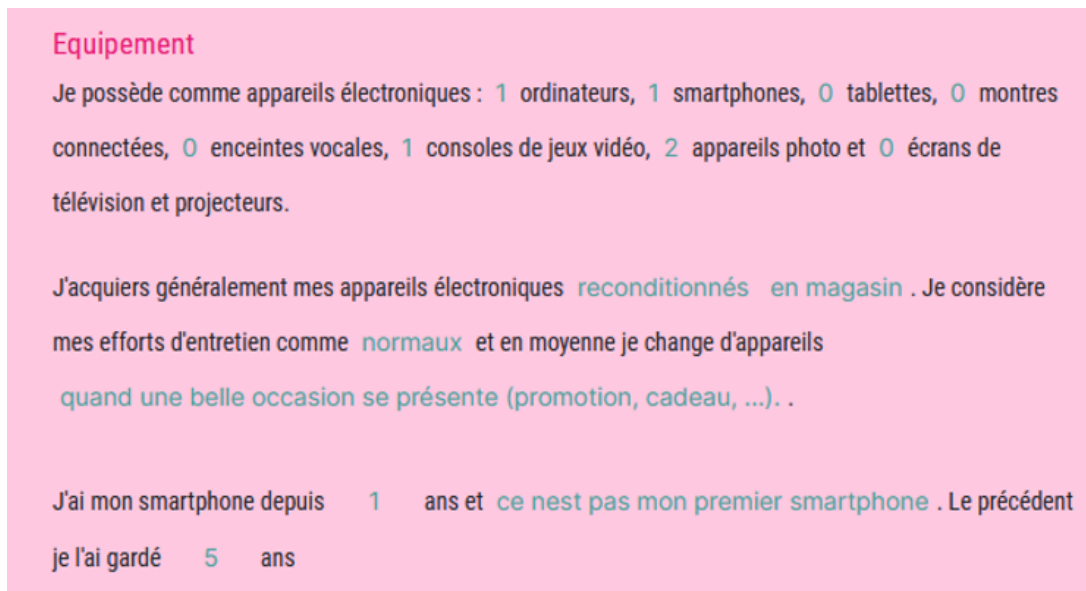
The objective of this section is for the user to quantify his consumption (number of devices, clothes, etc.) but also to measure the impact of the way of consuming.

Indeed, it is evident that the best way to consume for the environment is to consume less. However, the questionnaire also allows to compare different ways of consuming, considering that the user may find it less constraining to change his habits than to stop them.

The section is divided into five sub-modules: (electronic) devices, furniture and appliances, digital consumption, textile, and ultimately hygiene and cleaning.

2.4.6.1 Devices

In this first part is considered a list of electronic devices that the user could own. All are treated as of personal use and so are not distributed among the inhabitants. Additional information is requested about the mode of acquisition, delivery, as well as maintenance and replacement habits; Furthermore, the amortization of every device is chosen as five years [110], except for the smartphone, where additional information is requested. The display of an example of completion can be seen in figure 2.42



Equipement

Je possède comme appareils électroniques : 1 ordinateurs, 1 smartphones, 0 tablettes, 0 montres connectées, 0 enceintes vocales, 1 consoles de jeux vidéo, 2 appareils photo et 0 écrans de télévision et projecteurs.

J'acquiers généralement mes appareils électroniques reconditionnés en magasin . Je considère mes efforts d'entretien comme normaux et en moyenne je change d'appareils quand une belle occasion se présente (promotion, cadeau, ...).

J'ai mon smartphone depuis 1 ans et ce n'est pas mon premier smartphone . Le précédent je l'ai gardé 5 ans

Figure 2.42: Devices formulation

In this sub-module, the condition tree (see fig 2.43) contains two branches: the first is displayed if the user possesses at least one device, and the second is if he has at least one smartphone. Every variables description can be found in table 2.39

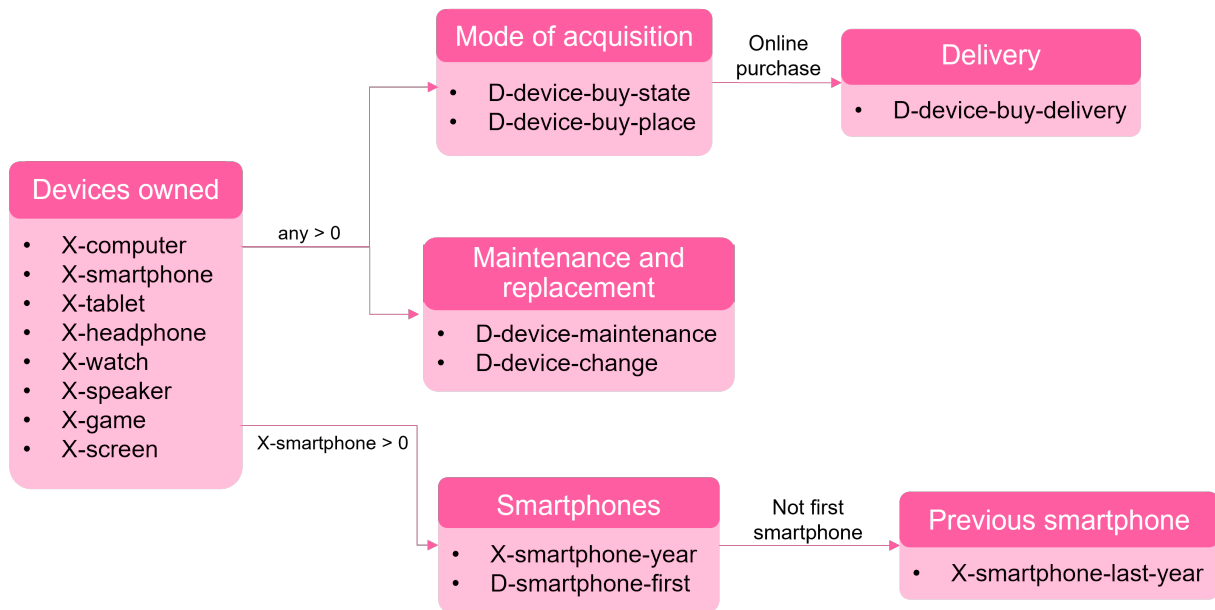


Figure 2.43: Devices conditions

In the first branch, in the question relative to the *Mode of acquisition*, **D-device-buy-state** differentiates the impact of the state of procurement of the device. If it is purchased "new", the full emission weight is added. If "refurbished", a reduction of 50% is accounted [111] and if acquired "used", 60% of reduction is made since it is assumed that a device used without refurbishment causes fewer emissions as no extra material or work has been done to it (intermediate transport, change of pieces, etc.).

Then, **D-device-buy-place** try to take into account the transport part of the accession. If "in stores" or "from hand to hand", the transport is considered in the mobility module. "Online", however, opens the subsequent *Delivery* question which specify the delivery option with **D-device-buy-delivery**, entailing additional emissions due to the package transport: with the assumption of a 1 kg package doing a first travel over 500 km in plane (with the example of a package coming from Frankfurt's Amazon warehouse [112] to Zaventem airport in Brussels), and a second travel in van of 80 km for the 2 first choice of **D-device-buy-delivery** or 40 km for the last one. The result will be divided by the amortization period.

The question *Maintenance and replacement*, for its part, focuses on the end life of the devices. The purpose of the question here is so to enlighten the behavior that leads to over-consumption. According to [113], 59% of high-tech devices are replaced while still working. This behavior is addressed in the report of [114], which described six main motivations to replace a piece of equipment: When it is non-repairable, to follow trends, when the reparation is more expensive than a replacement, to be up to date in term of technology, to gain comfort, to take advantage of a financial opportunity. The variable **D-devices-change** dropdown is inspired from those habits to appeal to every type of users; Also, the quality of care also has a consequent influence on the lifetime (most

Table 2.39: Description of devices's variables and hypothesis

Variables name	Description
X-computer	Number of computers
X-smartphone	Number of smartphones
X-tablet	Number of tablets
X-headphone	Number of headphones
X-watch	Number of connected watches
X-speaker	Number of speakers
X-game	Number of game consoles
X-camera	Number of cameras
X-screen	Number of screens, televisions and projectors
D-device-buy-state	State of devices at the time of purchase (new, refurbished, used)
D-device-buy-place	Place of the devices's purchase (Online, in shops, from and to hand)
D-device-buy-delivery	Place of the devices's delivery (At home, at relateive's home, in a relay)
D-device-maintenance	Level of the user maintenance for his devices (Low, Normal, High)
D-device-change	Reason of devices's change (broken w/o repair, broken after repair, broken too expensive to fix, new model, commercial opportunity)
X-smartphone-year	Age of the smartphones since purchase (yes, no)
D-smartphone-first	If the user had a smartphone before current
X-smartphone-year-last	Total lifetime of last smartphone
HYP-devices-duration	Devices amortization period (exc. smartphone)

smartphones end their life because of drops and shocks [115]).

The way chosen to take those behaviors into account in terms of CO_2e is to change the amortization period, each answer being associated with a change of the above-mentioned five years. The choices and coefficient are shown here below in tables 2.40 and 2.41

Table 2.40: Effect of change habits (**D-devices-change**) on the amortization period (**HYP-devices-duration**)

Choices	Effect
Broken w/o repair	-1 year
Broken after repair	+1 year
Broken too expensive to fix	-1 year
New model	-1 year
Commercial opportunity	-1 year

In the second branch, *Smartphones* specifies the duration of ownership of the current

Table 2.41: Effect of maintenance habits (**D-devices-maintenance**) on the amortization period (**HYP-devices-duration**)

Choices	Effect
Low	-1 year
Medium	no change
High	+1 year

smartphone and asks with **D-smartphone-first** if it is the first one of the user. If not, the question *Previous smartphone* appears for the user to enter his last smartphone lifetime. This is to help make an average: e.g., if someone changed his smartphone this year but kept the previous one for seven years, it is disadvantageous to simply count all the weight of his current smartphone in the yearly carbon assessment.

2.4.6.2 Furniture and appliances

For the furniture and household appliances, similarly to the shopping habits, it has been decided to take into account the user's carbon footprint if and only if the user is buying and choosing his equipment.

Furthermore, the emissions computation process is analogous to the devices submodule: quantities and types of objects are listed, and the description of acquisition and maintenance habits is asked, influencing the lifetime expected for the different furniture and appliances.

The structure of the question can be seen in figure 2.44 and 2.45 and the variables and hypothesis in table 2.42.

Meubles et électroménager

Je possède et achète moi-même mes meubles.

J'ai 1 canapés, 1 lits (sommier + matelas), 1 armoire/ dressing et 5 petits meubles (tables basse, chaises, ...).

Je ne possède pas et n achète pas moi-même mes appareils électroménagers.

En général, j'acquière un meuble/ électroménager d'occasion , et je recherche en premier un prix bas , et je considère mes efforts d'entretien comme normaux .

Figure 2.44: Furniture and appliances formulation

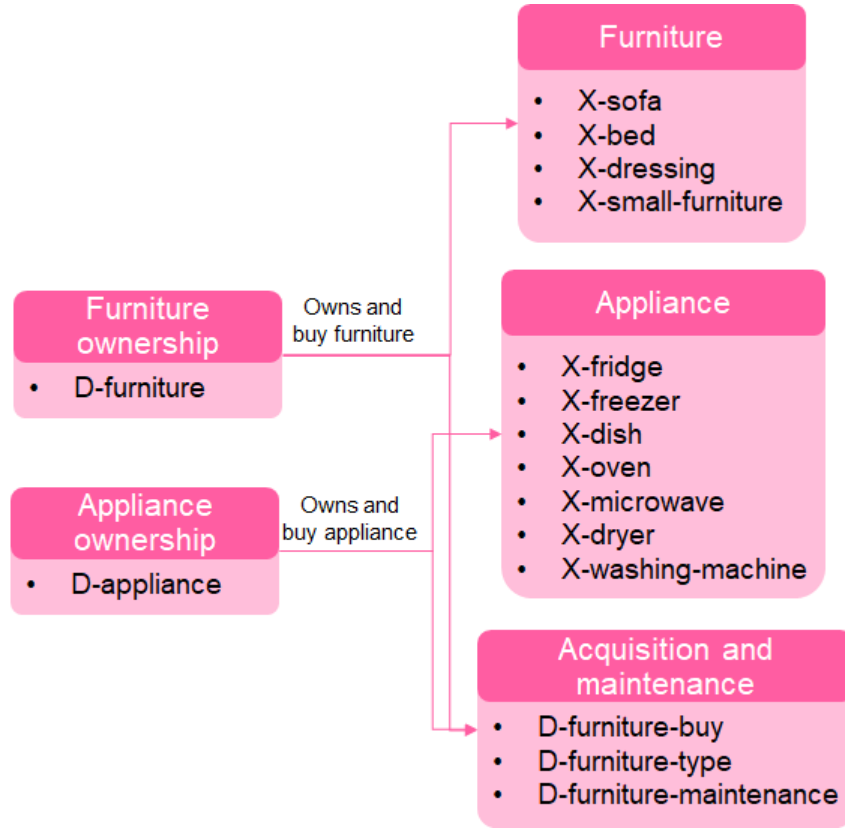


Figure 2.45: Furniture and appliances conditions

D-furniture and **D-appliance** have the same choices, leading to the apparition of the following question; Then, the user must fill a list of each category. It is non-exhaustive but still tries to take into account the main furniture and appliance of a household¹⁴; Finally, the user habits are requested in *Acquisition and maintenance*. It covers three aspects: The first concerns the state of acquisition: if bought used, the emissions will be divided by two. The second and the third variables play with the lifetime of the product and so with the amortization period.

It is well rooted in the mentalities that a low-price appliance means a shorter lifetime [114], and it is a belief largely corresponding to the reality [113]. For a similar product, it can vary between 9 and 16 years of longevity[113]; Furthermore, maintenance also plays a massive role in the state of appliances and furniture. According to [114], 47 to 70% of failures under warranty are due to lack of maintenance or misuse.

Those two questions can be related: the higher the cost, the better the care.

With an average lifetime for an appliance of around 11 years [116], the answers to the effects of the question are shown in table 2.43 for the quality and table 2.44 for the maintenance.

¹⁴Every EF from [19]; For the small furniture, will be taken the cost of a chair; Only for the dressing, the EF was divided by 3, due to the fact that the EF was based on a 300 kg dressing, which appear too large for the everyday dressing

Table 2.42: Furniture and appliances variables and hypothesis

Variables name	Description
D-furniture	If the user owns and buy his furniture (yes, no)
X-sofa	Number of sofas owned
X-bed	Number of beds owned
X-dressing	Number of dressings owned
X-small-furniture	Number of small furniture owned
D-appliance	If the user owns and buy his appliances (yes, no)
X-fridge	Number of fridges owned
X-freezer	Number of freezers owned
X-dish	Number of dishwashers owned
X-oven	Number of ovens owned
X-microwave	Number of microwaves owned
X-dryer	Number of dryers owned
X-washing-machine	Number of washing machines owned
D-furniture-buy	State of object at purchase (new, used)
D-furniture-type	Insentive of purchase of objects (Low price, high quality)
D-furniture-maintenance	Level of the user maintenance (low, normal, high)
HYP-appliance-duration	Amortization period

Table 2.43: Effect of purchase habits (**D-furniture-buy**) on the amortization period (**HYP-appliance-duration**)

Choices	Effect
Low price	- 2 years
High quality	+ 2 years

Table 2.44: Effect of maintenance habits (**D-furniture-maintenance**) on the amortization period (**HYP-appliance-duration**)

Choices	Effect
Low	- 2 years
Medium	No change
High	+ 2 years

Finally, the score is divided by the number of inhabitants in the flatshare or the number of inhabitants of the household if the user doesn't have one.

2.4.6.3 Digital

The consumption is not just physical; digital consumption also has responsibility for GHG emissions. Here is highlighted three online behavior: watching in streaming, listening to

music and using social media. Those actions entail various energy consumption, which, in a nutshell, can be divided into three main posts: data centers, data transmission and devices used.

By accounting for the different energy needs for each post, EF can be deducted, converting hours of digital consumption into GHG emissions. However, Decoding these inputs requires many assumptions to fit a global result, and various studies claim highly different outcomes.

Contrarily to previous sections, this submodule will first state two of the main current studies and the model chosen for the questionnaire and then expose the questions.

Contentious debate In this work has been investigated two sources: The Shift Project [117] and the International Energy Agency (IEA) [118]. The former has published results about digital consumption emissions questioned by the latter, which also released his proper model. The main difference between the two is exposed here below.

On the one hand, according to The Shift Project[117], online videos represent 60 % of the global data flow and are worth close to 1 % of the total GHG emissions [119] with an estimation of about 0.75 kWh of energy needed for one hour of viewing, with more than 85 % of this outcome due to the data transmission [120] and more than 10% for the data center.

On the other hand, the International Energy Agency (IEA) [118] states a vastly different resultant, with 0.078 kWh per hour of streaming composed this time more than 70 % of the device and more than 20% of the data center's [120].

The Shift Project answered in turn to the IEA [121] without changing its conclusions.

As seen, those different views induce very variable outcomes, with a factor of ten between the estimated footprint of one hour of streaming ($0.018 \text{ kgCO}_2\text{e/h}$ for the IEA and $0.197 \text{ kgCO}_2\text{e/h}$ for The shift project [120]).

To distinguish these two views on right or wrong is out of bounds of this thesis. However still, a choice needed to be made for this project, and the final decision was to follow the IEA because they provide an open calculator allowing the retrieval of data in Belgium with three factors (Bitrate, device, and network type). However, to be noted that the network type is not available equally for every device (4G being open only for tablets and smartphones).

Questions Going back to the questions, it can be seen that for the three parts (stream, music, and social media), the number of hours per day or week is asked. Howbeit, the conversion to kgCO_2e differs for each. Display, conditions and variables (in 2.46, 2.47 and 2.45).

Numérique

Je regarde des vidéos, lives, séries et films en streaming environ 12 heure(s) par semaine généralement sur mon ordinateur , en haute qualité (720p/1080p/HD) .

J'écoute de la musique en ligne en majorité avec de la 4G environ 2 heure(s) par jour.

Et je passe environ 4 heure(s) par jour sur les réseaux sociaux (Tiktok, Instagram, Facebook, Snapchat, ...), généralement avec du wifi

Figure 2.46: Digital formulation

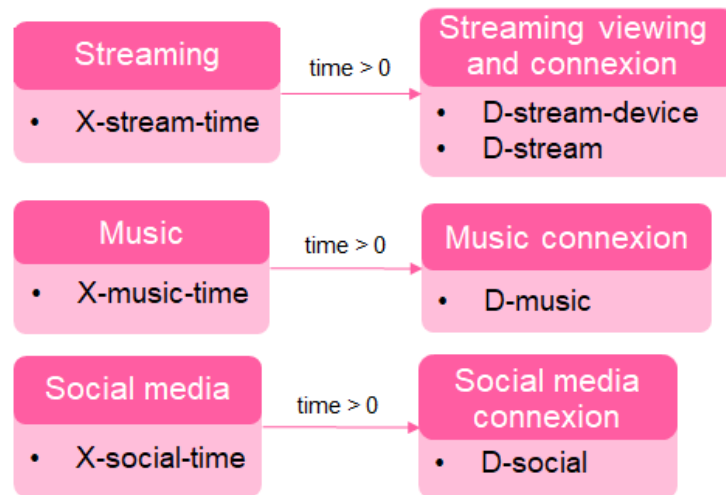


Figure 2.47: Digital conditions

Table 2.45: Digital variables

Variables name	Description
X-stream-time	Hours of streaming per week
D-stream-device	Device used for watching (smartphone, tablet, computer, TV)
D-stream	Quality of streaming (medium (480p/SD), high (720p/1080p/HD), very high (4K))
X-music-time	Hours of online music listening per day
D-music	Type of connexion (wifi, 4G, youtube)
X-social-time	Hours spent on social media per day
D-social	Type of connexion (Wifi, 4G)

In *Streaming viewing and connexion*, the IEA model explains the two pieces of information asked: **D-stream-device** and **D-stream**¹⁵).

Concerning the music, we have **D-music** that reaches for how to listen to it. If "youtube" is chosen, it is taken into account the cost of the video streaming as well, with the assumption that it is listened to from a computer, with the same quality chosen in **D-stream**. For the two other options, taking that an hour of music on Spotify [122] corresponds to a fifth of an hour of medium quality on Netflix [123], we will use the data from the IEA model divided by 5.

Finally, for social media, the estimation can be rather tricky as the time spent is shared between multiple activities: viewing images or videos, commenting, sending messages, etc. Some estimations [124, 125] give 1.5 MB/min, similar to viewing a video in 144p. For this question will be taken the bitrate "low, mobile default" from the IEA model, taking that the majority of the social media consumption is done with a smartphone [126].

2.4.6.4 Textile

The cost of the user's clothing in terms of emissions is described here to be the cost of the purchases he has made in the last 12 months. Display, conditions, and description are available in figure 2.48, 2.51 and table 2.47 respectively.



Figure 2.48: Textile formulation

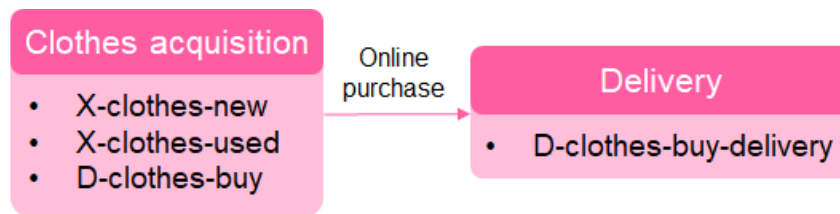


Figure 2.49: Textile conditions

All types of clothes are summarized into one category, so its EF is computed as the average of several pieces of clothing: Dress, sweater, t-shirt, shirt, pair of jeans, shoes, and jacket.

¹⁵As been extrapolated from the model the value for the UHD for smartphone and tablet, as they were not yet implemented

Table 2.46: Textile variables

Variables name	Description
X-clothes-new	Numbers of clothes bought new the last 12 months
X-clothes-used	Numbers of clothes bought used the last 12 months
D-clothes-buy	Place of the clothes's purchase (shop, hand to hand, online)
D-clothes-buy-delivery	Place of the delivery (home, relative's home, relay point)

X-clothes-new accounts for new clothes, and **X-clothes-used** for the ones acquired used. A used one is assumed to be worth half of a new one. Similarly, as in the *Devices* 2.4.6.1 sub-module, the **D-clothes-buy** choice clarifies the place of buying. The 2 last options don't add up anything as the trip is considered in the *Mobility* part, but the first, for its part, opens a new question *Delivery* and variable **D-clothes-buy-delivery**. The assumptions of the travel are the same as in 2.4.6.1, considering this time a package of 2 kg.

2.4.6.5 Hygiene

This last sub-module contain only one question, treating equally hygiene and cleaning products. The quantity is asked to all users, and habits of consumption for those who answered making their own groceries in the shopping sub-module 2.4.5.2. Again, display, conditions and variables are exposed (see 2.50, 2.51 and 2.47)

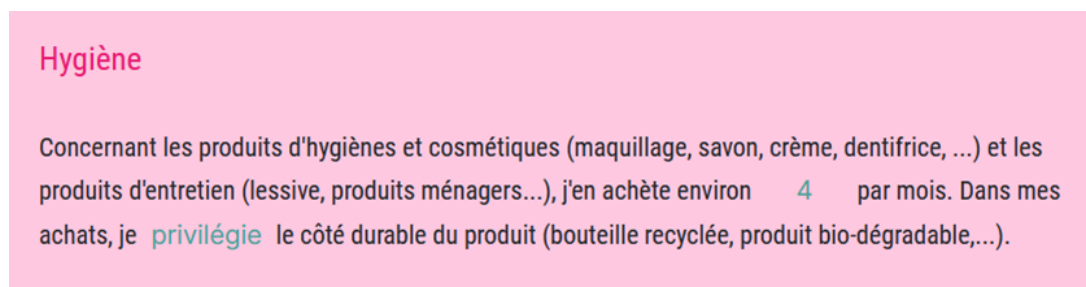


Figure 2.50: Hygiene formulation

Table 2.47: Hygiene variables

Variables name	Description
X-hygiene-cons	Number of personal hygiene and cleaning products bought per month
D-hygiene-buy	Sustainable products focus (yes, no)

All products are taken into account with a single variable. To do so, two pieces of information are needed: the average EF in $kgCO_2e/kg_{product}$ and the average weight. For

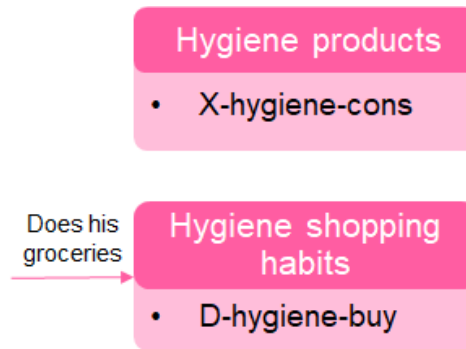


Figure 2.51: Hygiene conditions

the first one, has been chosen the average EF of multiple cosmetic and cleaning products: shampoo, shower gel, solid soap, Liquid dish-washing product, Multi-purpose cleaner, and Sanitary detergent. As for the second one, each product is assumed to weigh 1/2 kg.

It is noteworthy to mention that no pure cosmetic products are contained in the average emissions. They are all in the hygiene and cleaning category.

Indeed, overall little is known about the actual environmental impacts of cosmetic products [30]. The main source of information is the study "It's Time to Make up the future" [127], but it focuses on global emissions, giving the sector between 0.5 % and 1.5% of all GHG emissions. This is why the assumption of similar emissions to the cleaning and hygiene domain has been made.

In addition to the cost of the products, the focus on the choice is asked with **D-hygiene-buy** to favor focus on sustainable products. Using the result of [127], packaging and ingredients are believed to be worth respectively 20% and 10% of the product emission, or 30 % in total. Assuming that sustainable packaging and use of *environmentally friendly* ingredients could lower those emissions by half if the user favors sustainable products, the total cost will be multiplied by a factor of 0.85.

2.4.7 Final comment

This last section concludes the questionnaire. It does not include any questions that influence the user's carbon footprint. It solely reminds the non-exhaustive and nonabsolute aspect of the questionnaire, which, even if giving a precise mass of CO_2e , is riddled with assumptions, uncertainty, and hypothesis.

Here is the text shown:

Comme expliqué dans l'introduction, les différents modules qui viennent d'être complétés essaient au mieux de reprendre l'entièreté de ce qui est responsable d'émissions de gaz à effet de serre dans la vie d'un · e étudiant · e du supérieur. Il est évidemment impossible d'être complètement exhaustif, notamment car ce serait trop chronophage pour trouver les données: doivent s'ajouter par exemple les émissions communes à la société belge

(routes, hôpitaux, armé etc.), ainsi qu'une série d'impacts plus détaillés lié la vie de chaque étudiant · e (compte d'épargne, détails approfondis des modes de consommation, etc.).

Chapter 3

Results and discussion

Now that the questionnaire has been implemented, it is time to see its results. As a reminder, the goals pursued were to be able to adapt to the diversity of student profiles altogether while respecting the constraint of completion time (i.e., under 30 minutes).

The latter will be addressed first, comparing the minimal and maximum number of answers possible according to several profiles. Afterward, the adaptability of the model will be challenged through several *personae*, typical student profiles.

Subsequently, some improvements in the questionnaire will be addressed.

3.1 Completion time

The completion time is directly linked to the number of questions the user faces and the number of answers the user needs to enter to complete the questionnaire. Assuming that a user needs an average of 10 seconds per answer, computing the total number of inputs allows us to estimate the total time.

Aiming at including all possible users, which all can have different profiles and so different questionnaires, a *time gap* is formed by the extreme minimum and extreme maximum number of answers possible. *Extreme* because they do not represent any student's profile: they are computed with the sole purpose of maximizing or minimizing the number of answers (e.g., the minimal inputs assumes for the user no hobby, vacation, or week-ends in the mobility module). In figure 3.1, the result of this method is observed with four different profiles: student with no flatshare and of each of the three categories described in 2.4.3.1.

What emerges immediately is the preponderance of the mobility module for every maximum value, representing half of the total and the significant difference with its minimum value. It is because of the method explained just before: the minimum expects no licenses, no trips in a vehicle, no hobby or weekend or vacation, while the maximum assumes two vehicles, every single trip in vehicles (adding each time two answers due to the need to

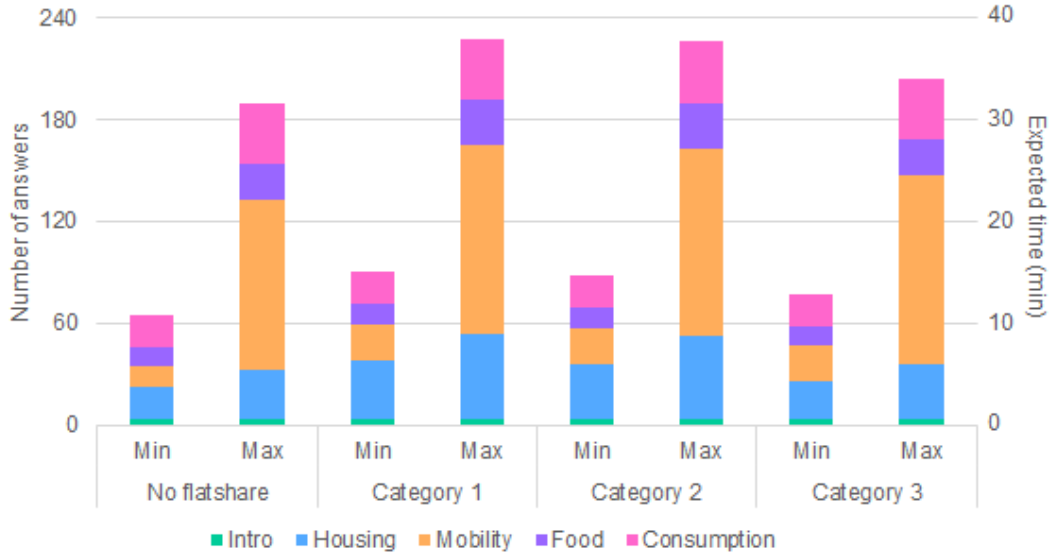


Figure 3.1: Minimal and maximum number of answers and expected completion time of the questionnaire, according to different student profiles. Categories refer to the housing repartition discussed in 2.4.3.1. Data are in appendix D.

choose the vehicle and to describe the number of persons sharing it), and the highest number of hobbies, weekends and vacations.

This partly explains why maximums exceed the 30-minute ceiling discussed at the beginning (see 2.1). The complexity of the student mobility (three different periods per year with potentially other behavior) and the duplication of displacements rise drastically in the number of questions required; Furthermore, the accumulation of two dwellings also explains this excess.

Fortunately, only the maximum overcome the 30 minutes. Another look at time completion is given with the *personae* to see what more probable profiles might get as questionnaires. With them, the adaptability of the questionnaire can also be challenged.

3.2 Personae

Three different student profiles have been created to test the adaptability of the questionnaire. With them, the survey can be completed following their lifestyle; These profiles are called *Personae*. They are in other terms *caricature* of selected student type that highlights certain common behaviors. They can be considered *semi-fictional* characters because they are created from scratch but simultaneously replicate plausible and coherent habits.

The idea is not to judge student behaviors but to show the results the developed tool can give with different entries.

For the three personae (named Alex, Émilie, and Lucas), a summary of their mindset and habits regarding housing, mobility, food, and consumption are given below. With this course of action, the questionnaire can be filled out, and their carbon footprint can be computed.

The results are displayed and discussed for each, followed by general comments written at the end.

3.2.1 Alex

Alex is entering his second year at the university. He is the eldest of the family and chose the car instead of the flatshare. He is, therefore, still living with his parents and younger sister. He does not believe in anthropogenic influence on climate and thinks this is just a natural change.

Housing His household is a beautiful four facades villa 30 km from the campus. It is an old house but has been renovated recently.

Mobility He is currently the only one using the car, but his sister will soon catch up and get her license. He will then have to share it.

He goes to every class at the university. During the study period, he prefers to work at the university's library to focus better. He makes most of his academic trips with a friend from the same neighborhood . His main hobby is to play hockey three times a week.

Regarding the vacations, every year in July, his family and him go on holiday together: they try to discover a new country every time, and go by plane to save time. This year, he also enjoyed a week in one friend's house in the South of France in September, and in January, he went skiing with the same group. Once in a while, he goes for a weekend at the sea or in the Ardennes.

Food At home, he does not deal with anything linked to groceries. In the evening, his parents cook, and for lunch, he uses what he can find in the fridge to save on his small budget to make his daily lunch. His family eats of everything, but particularly likes Asian food with poultry.

From time to time in the morning, his father prepares his famous hot chocolate, which puts the world in a good mood.

On the Weekends, he does not hesitate to go to the bar after hockey matches or with some friends.

Consumption He received a new set of electronic devices (computer, smartphone, etc.) for his studies. Also, he loves new branded clothing.

3.2.1.1 Carbon footprint

In figure 3.2 is represented the estimation of Alex's carbon footprint estimation.

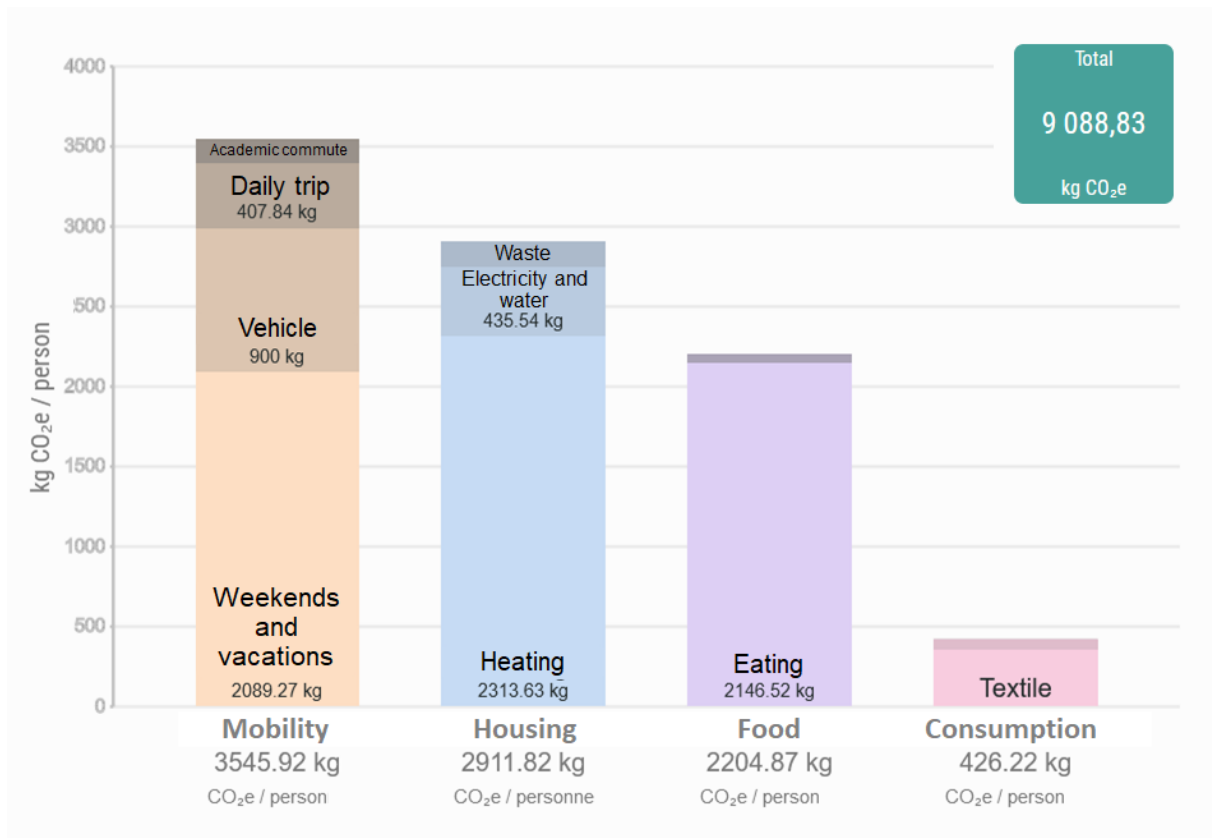


Figure 3.2: Alex's carbon footprint resulting from the questionnaire (translated).

His more extensive post is mobility, with more than half his weekend and vacation travels. As he is the only one driving his car, it is considered personal, and he gets the fabrication cost all for himself.

The second one is housing, widely from heating. Even if they are four living under the same roof, a large area to heat up and high-temperature habits lead to greater primary energy consumption.

The last modules mainly comprise eating and clothing purchases, as he does not shop for food or equipment. Also, the textile submodule can proliferate since the entire carbon footprint of the bought clothing is accounted for in the first year, contrary to the devices that are amortized over five years.

3.2.2 Émilie

Émilie enters in Master's at the university. She is very preoccupied with the climate crisis and the problems it causes worldwide. She tries to make the change at her scale but makes some exceptions for her well-being.

Housing She lives in a theme-based flatshare (flatshare with a project during the year) with seven other people during the week and goes back most of the weekends to her mother’s home. Her flatshare is old and seedy, but at least the rent is not too expensive. They try to limit heating, but the building state does not help to keep the heat. In her household, she lives with her mother in a small apartment in the South of the country. They also pay attention to heating and electricity so as not to consume too much.

Mobility She has no license (yet). She takes the train to go to her flatshare. Fortunately, it is on campus, so she can attend her courses on foot.

Her weeks are packed with her project, so she does not have to move far.

However, one thing she can’t give up on is vacation. She loves to travel to discover new cultures. She tries to leave by plane to faraway countries 2 to 3 times a year, sometimes with her family, but especially with 1 or 2 close friends.

Food After seeing many documentaries about animal mistreatment, she decided to become 100% vegan. A choice that her mother respects.

Big fan of tea, she can’t study without it. The theme-based flatshare life makes her participate in several parties during the week, but it’s quieter the WE.

She does all her shopping at local and fair trade cooperatives on campus.

Consumption Long-time repair coffee subscriber, she tries to keep her devices as long as possible, even if she does not have a lot: she gave up her smartphone in favor of an indestructible old brick and had a PC for classes.

She buys all her clothes at thrift shops and carefully selects hygiene products for the planet.

3.2.2.1 Carbon footprint

In figure 3.2 is represented the estimation of Émilie’s carbon footprint estimation. The order of the modules is the same as for Alex’s footprint, but their magnitude is different. As expected of this personae, the carbon footprint is dominated by vacations, mainly because of plane travels.

The housing module’s footprint is more equitably shared between the submodules. As her mother’s apartment is less than 40 years old, there is still a 40th of the fabrication’s amortization to pay. Furthermore, the heating is relatively low compared to Alex’s because of the small area and low-temperature habits.

The vegan habits and groceries efforts pay off in terms of reduced footprint: the shopping submodule is not displayed because it has a negative value (850 $kgCO_2e$ for eating and 750 $kgCO_2e$ for all module, translating a -100 $kgCO_2e$ for the shopping submodule).

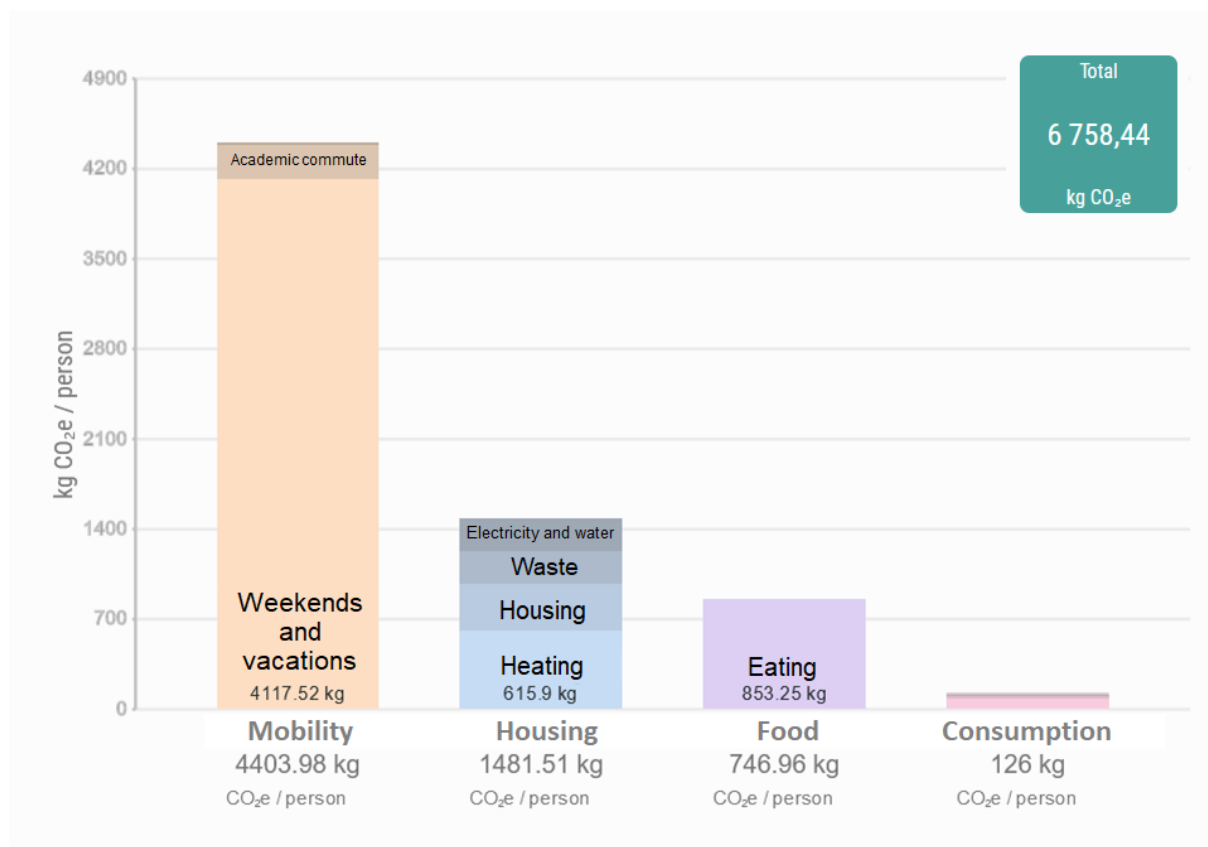


Figure 3.3: Émilie's carbon footprint resulting from the questionnaire (translated).

Finally, the consumption can be considered negligible compared to the total, representing less than two % of her carbon footprint.

3.2.3 Lucas

Lucas can be called an independent student. Finishing his master in *haute-école*, he only goes back to his parents once or twice a month to see them and say hello. He remains in a single apartment most of the year. The changing state of the planet worries him. However, he blames large corporations for it and thinks individuals don't have barely any influence on it compared to them.

Housing The single apartment is small but comfy. On the other hand, it is cold in winter, so it is necessary to raise the heaters so as not to catch a cold (anyway, the charges are included in the rent). They have small heaters for the coldest nights. As the charges are in his name, he knows his consumption precisely.

Mobility To find cheaper rent, he is not near his campus. Fortunately, he received from his uncle a scooter to make the trips to school. In his *haute école*, classes are mandatory. His scooter also allows him to go to his piano lessons on Friday. He has a student job on weekends, but luckily he can go on foot.

As for weekends and holidays, given his small budget, he does not travel much. He leaves once a year for a week city trip (with the cheapest option: a low-cost airline) and enjoys his aunt's beachfront house for some weekends.

Food He does his shopping but has the cheapest and easiest goal. Since he dislikes making them, he buys lots of frozen food to avoid accumulating trips. Lover of butchers; for him, a good meal is a meat meal.

He is a great consumer of coffee, he cannot wake up without it. Also, worshipper of the spring water of the Ardennes, he drinks a lot of it in bottles. Finally, he does not like beer, but he occasionally opens a bottle of red wine.

Consumption Fans of video games, he has all the equipment he needs to enjoy it to the fullest(which he orders online): a large part of his salary is spent there. He is very painstaking towards them.

As they planned to move together with his girlfriend into an apartment after the master thesis was submitted, he began to search for second hands furniture and appliances.

All the time connected, he only works with listening to music. Having a horror of shopping, he only buys clothes when strictly necessary.

3.2.3.1 Carbon footprint

Lucas's carbon footprint estimation is shown in figure 3.2. He has the lowest footprint of the three personae and with a different module's distribution: his footprint is dominated by food.

His large eating footprint is mainly explained by his meat habits. Then, mobility can be seen as low compared to the two previous footprints since his vacations are limited, and he owns a small vehicle.

Finally, in consumption, the device's submodule is the largest. First, because he owns lots of it, and second it is lower than furniture and appliances due to the difference in amortization period (11 years on average instead of 5).

This concludes the presentation of the three personae. Here be addressed their approximated completion time and global comments on their results.

3.2.4 Personae's completion time

The number of answers per module for each personae is shown in figure 3.5. A first look gives that all are below 30 minutes (again, assuming 10 seconds per answer).

The longest module stays the mobility for all, but its size is far more reasonable compared to its maximum length. The housing module is longer for Émilie, as she has to describe

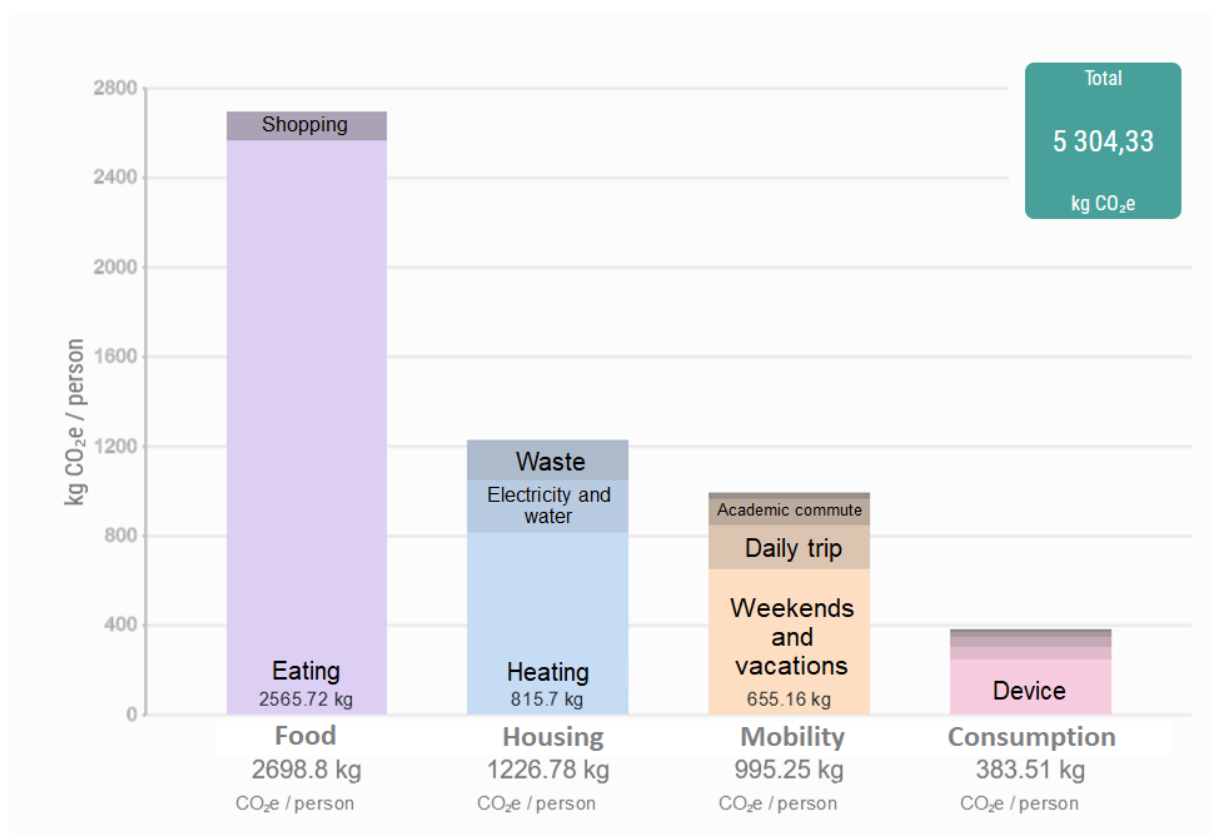


Figure 3.4: Lucas's carbon footprint resulting from the questionnaire (translated).

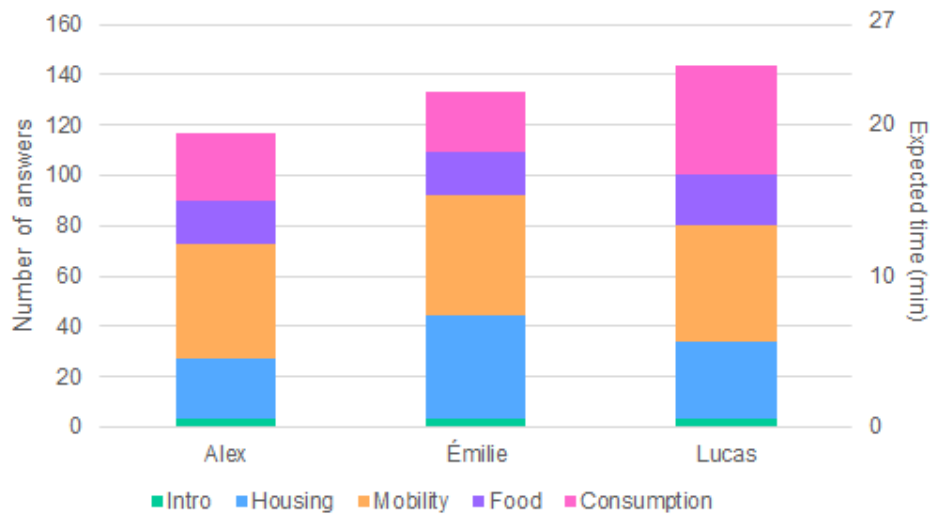


Figure 3.5: Number of answers for the three personae.

both her household and flatshare, contrary to the others. Moreover, Lucas is the only one to purchase furniture and appliances, so his consumption module is larger.

Instead of looking at each module separately, we can also put in perspective the total footprints.

3.2.5 General comments

Across the three profiles, several similarities can be noticed. First, in the housing module heating is systematically the most significant component. Also, Vacation can have a massive influence in comparison to other trips as soon as the user has plane travel.

The total footprint is 9 tons of CO_2e for Alex, 7 for Émilie, and 5 for Lucas. Those estimations are all below the national average, which is between 10 and 20 tons of CO_2e per inhabitant [14, 15] (even if those three personae are just a sample). Several points can explain this gap :

First, as mentioned in the *Final comment* 2.4.7, the questionnaire does not take into account public services (hospitals, roads, army, public administration, etc.) that should be shared between every Belgian citizen equally. Furthermore, investments are also neglected but are included in the national footprint.

Second, about the model around the responsibility of choices: in several sub-module of the questionnaire (vehicle, shopping, furniture, appliances, etc.), the emissions are not accounted for if the user does not have a direct decision. This could lower the estimation because a student still benefits from specific attributes despite not choosing them. Nevertheless, this influence can be considered relatively small given the three footprints computed: the only one without shopping decisions, Alex, has the most significant footprint, while the one with all the responsibilities, Lucas, got the lowest footprint.

Third, their housing-linked emissions can be reduced due to students tending to live with several people (family households or flatshare). The total of people is usually larger than the country's average household (2.2 people per household in Wallonia in 2021 [128]).

Ultimately, models, partial data, and approximations utilized in the questionnaire may introduce a degree of imprecision, potentially resulting in the underrepresentation of certain facets of student life; (e.g. by underestimating the housing area for dwellings deviating from average, modeling the heating need with limited details or with the shopping habits based on reduced data). As demonstrated within this thesis, numerous assumptions have been incorporated to construct the survey.

Nevertheless, these three personae showed that the survey can adapt to various student profiles with very different life habits and in the allotted time, respecting the goals fixed at the beginning of this thesis. Yet, it is not that it cannot be improved or can stay consistent through time.

3.3 Evolving sector and possible add-on

The questionnaire models and assumptions were built upon existing data about the Belgian, Walloon, and Brussels lifestyles. Yet, Belgian society and habits evolve with time, meaning the models will one day be outdated; In addition, EFs also have a validity date, updated year after year for accuracy to the current state of society.

This entails the need to update the questionnaire in terms of values (EFs, average data, etc.) and questioning (adding solar panels, etc.); Moreover, a series of improvements are possible today but not implemented due to lack of time.

Thus, for each module, areas for improvement and add-on applicable immediately or in the near future are listed below:

Housing

- Addition of pets
- Boarding school as an alternative to flatshare for the student second dwellings.
- Solar panel option.
- Sporadic heating habits (some people tend to heat just a few rooms instead of all their homes when needed).
- Wood consumption meter

Mobility

- For vehicles description, adding hydrogen motorization and precision about the type of car (city cars, sedans, SUV, etc.)
- In the daily commute, travels option about student jobs.
- In vacation and weekends, for users traveling more than the current number of possible trips (four weekends and three vacations), either increasing of the maximum or implementing a system to account for more (e.g., the fifth weekend worth the average of the four described; Similarly to the daily commute, let him add the remaining non accounted travels in two or more variables; etc.)
- Inclusion of trips to go on exchange (Erasmus, etc.)

Food

- In the shopping habits, addition of organic food shopping.

Conclusion

This work aimed to elaborate a carbon accounting tool tailored for French-speaking Belgian higher education students compliant with existing methodologies while being completable within a concise timeframe of under 30 minutes and able to adapt to the plurality of the targeted audience profiles.

Following the GHG protocol’s recommendations [16], translated to an individual life, the information needed was determined. To appeal to the general public, this information was rearranged into a questionnaire with a first-person narrative with the help of the designed tool from X-factor [129] and AWAC [26]. The resulting survey was structured into four distinct sections: housing, mobility, food, and consumption.

Within each module, through different assumptions and models based on data pertaining to Belgian society and emissions factors, the information collected is translated to a mass of equivalent CO_2 emissions, which serves as the standard unit of measurement for every GHG. Summed up, those masses form the annual carbon footprint of the user.

Once the questionnaire was established, to challenge it on the different objectives, several *personae*, caricatural profiles, were created and used to fill it. This process gauged the tool’s adaptability and facilitated a comparison of its results to the national average. While some room for improvement exists, it has been shown to be adaptable. From the comparison emerges a predictable underestimation due to the absence of incorporating specific posts like investment and public services into the user footprint. Furthermore, the minimum and maximum time completion have been computed, revealing potential instances of exceeding the 30-minute limit. Fortunately, this excess is expected to be infrequent due to the maximum computation method; this opinion is reassured by the three *personae*’s completion times, all of which fell within the established limit.

Overall, the resultant tool allows a French-speaking Belgian higher education student to compute his or her carbon footprint and through it to understand which of his or her behaviors exert a more significant (negative) environmental impact and what change could mitigate it.

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Appendix A

Questionnaire introduction text

Etablir son bilan carbone

Il vous est proposé de réaliser ici votre Bilan Carbone individuel en tant qu'étudiant belge du supérieur, c'est-à-dire votre impact sur le changement climatique. Même si une série de questions ont trait à l'ensemble des personnes avec qui vous vivez, le nombre de personnes est chaque fois pris en compte pour établir votre chiffre individuel. Ce calculateur est conçu de la manière la plus générique possible mais à ce titre ne colle pas à 100% à tous les parcours de vie. Il s'adresse aux étudiants du supérieur (hautes écoles, universités...) divisant leur temps de vie entre le campus (avec ou sans kot) et leur cadre de vie familial.

Une unité unique: les kilos de CO_2e

Un bilan carbone ou "bilan de gaz à effet de serre" se calcule sur l'ensemble des gaz qui ont un impact sur le changement climatique. Le CO_2 n'est pas le seul gaz à effet de serre (GES), loin de là. Il en existe toute une série, dont le potentiel de réchauffement est très variable, de même que leur durée de vie dans l'atmosphère. Les principaux sont : la vapeur d'eau (H_2O), d'origine essentiellement naturelle, le méthane (CH_4) et le protoxyde d'azote (N_2O). Pour toutes ces raisons, on exprime l'impact de tous ces GES par rapport au CO_2 , le GES le plus abondant après la vapeur d'eau, qui sert donc d'étalon. C'est ce qu'on appelle l'équivalence en CO_2 , que l'on note CO_2e .

Un périmètre large mais simplifié

Le périmètre des questions est volontairement large pour tenir compte de l'ensemble de nos activités humaines. Votre bilan n'est donc relativement complet que lorsque vous avez répondu à l'entièreté des questions. S'agissant d'un outil grand public, nous avons veillé toutefois à simplifier tout ce qui pouvait l'être, moyennant diverses hypothèses. A noter que le questionnaire est pensé pour être complété dans l'ordre, module par module, puisque certaines questions dépendent de vos réponses précédentes.

Les **INFO** répartis dans le texte vous permettent d'accéder à des informations complémentaires tandis que les **CLEFS** vous permettent d'accéder à un mode avancé où vous pouvez corriger nos hypothèses en encodant vos données réelles de consommation lorsque vous les connaissez.

Appendix B

Emissions accounting norms comparison

MÉTHODE RÉGLEMENTAIRE VERSION 5 ET ISO/TR 14069		BILAN CARBONE®		GHG PROTOCOL	
Catégorie	Poste	Poste	Scope	Catégorie	
1. ÉMISSIONS DIRECTES DE GES	1.1 Emissions directes des sources fixes de combustion	Energie	Scope 1	Emissions directes des sources fixes de combustion	
	1.2 Emissions directes des sources mobiles de combustion	Transport Déplacements		Emissions directes des sources mobiles de combustion	
	1.3 Emissions directes des procédés hors énergie	Hors énergie		Emissions directes des procédés physiques ou chimiques	
	1.4 Emissions directes fugitives	Hors énergie		Emissions directes fugitives	
	1.5 Emissions issues de la biomasse (sols et forêts)	Inexistant		Information optionnelle	
2. ÉMISSIONS INDIRECTES ASSOCIÉES À L'ÉNERGIE	2.1 Emissions indirectes liées à la consommation d'électricité	Energie	Scope 2	Emissions indirectes liées à la consommation d'électricité	
	2.2 Emissions indirectes liées à la consommation d'énergie autre que l'électricité	Energie		Emissions indirectes liées à la consommation de vapeur, chaleur ou froid	
3. ÉMISSIONS INDIRECTES ASSOCIÉES AU TRANSPORT	3.1 Transport de marchandise amont	Transport		4. Transport et distribution amont	
	3.2 Transport de marchandise aval	Transport		9. Transport et distribution aval	
	3.3 Déplacements domicile-travail	Déplacements		7. Déplacements domicile-travail des employés	
	3.4 Déplacements des visiteurs et des clients	Déplacements		Inexistant	
	3.5 Déplacements professionnels	Déplacements		6. Voyages professionnels	
4. ÉMISSIONS INDIRECTES ASSOCIÉES AUX PRODUITS ACHETÉS	4.1 Achats de biens	Intrants	Scope 3	1. Produits et services achetés	
	4.2 Immobilisations de biens	Immobilisations		3. Activités associées à l'énergie et aux combustibles	
	4.3 Gestion des déchets	Déchets directs		2. Biens immobilisés	
	4.4 Actifs en leasing amont	Dépend du type d'actif		5. Déchets générés par les opérations	
	4.5 Achats de services	-		8. Actifs en leasing amont	
5. ÉMISSIONS INDIRECTES ASSOCIÉES AUX PRODUITS VENDUS	5.1 Utilisation des produits vendus	Utilisation		1. Produits et services achetés	
	5.2 Actifs en leasing aval	Dépend du type d'actif		11. Utilisation des produits vendus	
	5.3 Fin de vie des produits vendus	Fin de vie		13. Actifs en leasing aval	
	5.4 Investissements	Inexistant		12. Traitement de fin de vie des produits vendus	
6. AUTRES ÉMISSIONS INDIRECTES	6.1 Autres émissions indirectes	Inexistant		15. Investissements	
				Inexistant	

Figure B.1: Comparison between categories and positions established between the national reference system, the *Bilan Carbone* and the GHG protocol, from [methode-pour-la-realisation]

Appendix C

Meals

C.1 Breakfast

C.2 Lunch/dinner

Table C.1: Breakfast EF

Ingredients	Qty <i>g</i>	FE <i>kgCO₂e/kg</i>	<i>gCO₂e</i>	FE <i>kgCO₂e/kg</i> Local	<i>gCO₂e</i> Local
Breakfast 1: Continental					
Bread	50	0.67	33.5	0.60	30.15
Pastries	50	1.7	85	1.61	80.50
semi-salted butter	10	7.82	78.2	7.71	77.05
Jam	20	1.42	28.4	1.29	25.70
Orange	100	0.64	64	0.47	46.50
Total	230		289.1		259.90
Breakfast 2: Dairy products and cereals					
Cow milk option					
Cereals	60	3.4	204	3.27	196.20
Dairy product	200	1.32	264	1.22	244.00
Total	260		468		440.20
Soya milk option					
Cereals	60	3.4	204	3.27	196.20
dairy product	200	0.44	88	0.37	74.00
Total	260		292		270.20
Oak milk option					
Cereals	60	3.4	204	3.27	196.20
dairy product	200	0.54	108	0.47	93.00
Total	260		312		289.20
Breakfast 3: Britannic					
Ham	100	7.1	710	7.01	700.5
Eggs	100	3.19	319	3.12	311.5
Oil	7	1.00	7	0.88	6.16
Toasts	50	1.76	88	1.70	85
Total	257		1124		1103.16
Breakfast 4: Vegan					
Banana	120	2.17	260.4	2.09	250.2
Kiwi	100	0.99	99	0.79	79
Apple	150	0.4	60	0.27	40.5
Total	370		419.4		369.7

Table C.2: Vegan meal

Ingredients	Qty <i>g</i>	FE <i>kgCO₂e/kg</i>	gCO ₂ e	FE <i>kgCO₂e/kg</i> Local	gCO ₂ e Local
Starters:					
Greek-style vegetables					
Tomatoes (out of season)	200	1.96	392.00	1.82	363.00
Fresh walnuts	10	4.17	41.70	4.04	40.40
Olive oil (1/2 tbsp)	7	1.00	7.00	0.88	6.16
Main course:					
marinated tofu. potatoes and onions					
Tofu	150	0.67	100.50	0.58	87.00
Potato	200	0.37	74.00	0.30	59.00
Oinon	50	0.39	19.5	0.27	13.25
Olive oil (1/2 tbsp)	7	1.00	7.00	0.88	6.16
Dessert:					
Fruit salad					
Stawberries (out of season)	200	0.55	110.00	0.43	85.00
Bread	50	0.67	33.48	0.60	30.15
Total	874		785.18		690.12

Table C.3: Soft vegetarian meal

Ingredients	Qty <i>g</i>	FE <i>kgCO₂e/kg</i>	gCO ₂ e	FE <i>kgCO₂e/kg</i> Local	gCO ₂ e Local
Starter:					
Tomato soup					
Tomatoes (out of season)	200	1.96	392.0	1.82	363.00
fresh cream	10	2.45	24.5	2.40	24.00
Main course :					
Potato and onion omelette					
2 eggs	100	3.19	319	3.12	311.5
potato	200	0.37	74	0.30	59
onion	50	0.39	19.5	0.27	13.25
olive oil (1/2 tbsp)	7	1.00	7	0.88	6.16
Dessert :					
Cheese and fruit salad					
strawberries (out of season)	200	0.55	110.00	0.43	85.00
soft cheese	25	5.42	135.5	5.3	132.9
Bread	50	0.67	33.5	0.6	30.1
Total	842		1115.0		1024.93

Table C.4: Medium vegetarian meal

Ingredients	Qty <i>g</i>	FE <i>kgCO₂e/kg</i>	gCO ₂ e	FE <i>kgCO₂e/kg</i> Local	gCO ₂ e Local
Starters:					
geek-like vegetables					
Vegetables (tomato)	200	1,96	392,0	1,82	363,00
Olive oil (1/2 tbsp)	7	1,00	7	0,88	6,16
Egg	50	3.19	159.5	3.12	156
Main course:					
Tartiflette végétarienne					
Soft cheese	100	5,42	542	5,3	530
Tofu	100	0.67	67	0.58	58
Potato	200	0,37	74	0,30	59
Onion	50	0,39	19,5	0,27	13,25
Olive oil (1/2 tbsp)	7	1,00	7	0,88	6,16
Dessert:					
Peer pie					
Peer pie	100	2.62	262	2.54	254
Total	814		1533		1445.09

Table C.5: White meat meal

Ingredients	Qty <i>g</i>	FE <i>kgCO₂e/kg</i>	gCO ₂ e	FE <i>kgCO₂e/kg</i> Local	gCO ₂ e Local
Starters:					
Greek-style vegetables					
Tomatoes (out of season)	200	1.96	392	1.82	363
Olive oil (1/2 tbsp)	7	1.00	7	0.88	6.16
Main course:					
Rice chicken					
Chicken	150	8.18	1227.1	8.07	1210.2
Rice	60	2.76	165.6	2.61	156.6
Dessert:					
Cheese plateau					
Soft cheese	25	5.42	135.5	5.32	132.875
Hard cheese	25	5.49	137.25	5.40	134.875
bread	50	0.67	33.5	0.60	30.1
Total	517		2097.9		2033.9

Table C.6: Red meat meal

Ingredients	Qty <i>g</i>	FE <i>kgCO₂e/kg</i>	gCO ₂ e	FE <i>kgCO₂e/kg</i> Local	gCO ₂ e Local
Starters:					
Tzatiki					
Yoghurt	125	2.12	265	2.03	253.75
Cucumber	75	0.47	35.25	0.35	26.25
Olive oil (1/2 tbsp)	7	1.00	7	0.88	6.16
Main course:					
Steak with fries					
Red meat	150	32.45	4866.8	32.36	4853.9
Potato	200	0.37	74.00	0.30	59.00
Dessert:					
Peer pie					
Peer pie	100	2.62	262	2.54	254
Total	657		5510.0		5453.0

Table C.7: White fish meal

Ingredients	Qty <i>g</i>	FE <i>kgCO₂e/kg</i>	gCO ₂ e	FE <i>kgCO₂e/kg</i> Local	gCO ₂ e Local
Starters:					
Greek-like vegetables					
Vegetables (tomato)	200	1.96	392	1.82	363.00
Olive oil (1/2 tbsp)	7	1.00	7	0.88	6.16
Main course:					
White butter fish					
White fish	150	9.4	1410.2	8.86	1329.24
Rice	60	2.76	165.6	2.61	156.60
White butter sauce	30	4.37	131.1	4.25	127.50
Dessert:					
Peer pie					
Peer pie	100	2.62	262	2.54	254
Total	547		2367.9		2236.5

Table C.8: Fat fish meal

Ingredients	Qty <i>g</i>	FE <i>kgCO₂e/kg</i>	gCO ₂ e	FE <i>kgCO₂e/kg</i> Local	gCO ₂ e Local
Starters:					
Greek-like vegetables					
Vegetables (tomato)	200	1.96	392.00	1.82	363.00
Olive oil (1/2 tbsp)	7	1.00	7.00	0.88	6.16
Main course:					
Salmon pie					
Salmon	100	6.12	612.1	5.71	571.16
Puff pastry	60	3.64	218.4	3.54	212.10
Pasteurised semi-skimmed milk	5	1.32	6.60	1.22	6.10
Light cream	5	2.45	12.25	2.40	12.00
Egg. raw	37.5	3.19	119.63	3.12	116.81
Dessert:					
Peer pie					
Peer pie	100	2.62	262	2.54	254
Total	514.5		1630.0		1541.3

Appendix D

Completion time data

Table D.1: Completion time data

Module	Sub-module	Number of answers							
		No flatshare		Category 1		Category 2		Category 3	
		Min	Max	Min	Max	Min	Max	Min	Max
Intro		3	4	3	4	3	4	3	4
Housing	FLATSHARE	1	1	4	4	4	4	4	4
	BUILDING	6	7	12	14	12	14	6	7
	HEATING	4	4	8	8	7	7	5	5
	ELEC-WATER	6	6	7	7	6	6	6	6
	METERS	0	3	0	5	0	5	0	3
	WASTE	2	7	4	12	4	12	2	7
	TOTAL	19	28	35	50	33	48	23	32
Mobility	Vehicule	1	12	1	12	1	12	1	12
	Commute	6	15	14	25	14	25	14	25
	daily	4	37	4	37	4	37	4	37
	Vacation	2	37	2	37	2	37	2	37
	TOTAL	13	101	21	111	21	111	21	111
Food	FOOD	9	15	9	15	9	15	9	15
	COURSE	2	6	3	12	3	12	2	6
	TOTAL	11	21	12	27	12	27	11	21
Consumption	Devices	8	8	8	8	8	8	8	8
	furnitures	2	16	2	16	2	16	2	16
	digital	4	7	4	7	4	7	4	7
	textile	3	3	3	3	3	3	3	3
	hygiene	2	2	2	2	2	2	2	2
	TOTAL	19	36	19	36	19	36	19	36
TOTAL GLOBAL		62	186	87	224	85	222	74	200

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