Environmental "Food"print of the University Canteen

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Abstract

The Green Office aims to gain insight into the quantified environmental impact of the university's canteen menu and develop a communication tool to inform consumers about the environmental impact of their food choices. This report describes the research underlying the development of the Food Environmental Impact (FEI) Model and the design of an environmental food label to communicate the environmental impact of food products to consumers. The FEI Model quantifies and compares the environmental impact of individual ingredients and recipes in terms of global warming, terrestrial acidification, freshwater eutrophication, marine eutrophication, land use, and water use, as well as the nutritional value in terms of protein and energy content. The model results can be used to identify "hotspot" ingredients in recipes and develop a communication tool in the form of an environmental food label. The proposed design of a communication tool is a multi-traffic light food label that displays three strongly positive correlated impact indicators: global warming, terrestrial acidification, and marine eutrophication. This food label format provides the best balance between ease of interpretation and completeness in providing information on different environmental concerns.

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Abbreviations

CH4 Methane

CO2 Carbon dioxide

FAO Food and Agriculture Organization

FEI Food Environmental Impact

FU Functional Unit

GHG Greenhouse gasses

LCA Life Cycle Assessment

LCIA Life Cycle Impact Assessment

LCI Life Cycle Inventory

MTL Multi-traffic light

N2O Nitrous oxide

NEVO Dutch Nutrition Database

RIVM National Institute of Public Health and Environment

SO2 sulphur dioxide

STL Single traffic light

UNEP United Nations Environment Programme

UoG University of Groningen

Introduction

Sustainability is one of the core values of the University of Groningen (UoG). As a socially responsible institution, the UoG has set the goal of incorporating sustainable development into all aspects of the university. The Green Office, comprised of students and staff, is part of the university's Sustainability Program. They coordinate and initiate projects related to sustainability. In collaboration with various partners within the UoG, The Green Office has drawn up a Roadmap of Sustainability with various sustainability objectives for 2021-2026 (UoG, 2021). One of the goals of the Green Office within this roadmap is to reduce the environmental impact of the canteen menu of the UoG.

Food systems are responsible for about 26% of global greenhouse gasses (GHG) emissions (CO2, CH4, N2O), about 70% of freshwater use, and occupies more than one-third of all potentially cultivable land. Larger values are predicted if mitigation actions are not being put in place (Batlle-Bayer et al., 2021) (Aleksandrowicz, Green, Joy, Smith, & Haines, 2016) (Ritchie & Roser, 2020). According to Springmann, a dietary shift is one of the key elements to reducing the environmental impact of food systems (Springmann et al., 2018). With the increasing popularity of food away from home, an important action concerning public meals is to implement and promote healthier diets that are low in carbon in educational institutions and all municipal dining rooms (Batlle-Bayer et al., 2021) (Dai, Yang, Lee, Fleischer, & Wemhoff, 2020). The problem with promoting more sustainable consumption is that consumers are rarely given information about the environmental impact of various food choices. Thus environmental sustainability is not a criterion for their meal choices (Dai et al., 2020). One common way to motivate food consumption changes and inform the consumer is through environmental food labels. Environmental impact food labels can help consumers compare food products and make more sustainable and environmentally conscious decisions (Osman & Thornton, 2019)

The environmental impact of the canteen menu can be reduced in two ways: first, by changing the menu by replacing high-impact foods with lower-impact foods, and second, by educating consumers about the environmental impact of their food choices and motivating them to choose the more environmentally friendly food option. In both cases, the current environmental impact of the various food items must be quantified first. The Green Office is currently lacking information about the quantified environmental impact of food items available in the canteen. This study aims to fill in the gaps in knowledge by developing a model that can quantify the environmental impact of various individual ingredients and recipes. The model allows users to compare the environmental impact of various foods and identify "hotspot" ingredients and recipes. The model results can be used to create a communication tool that will inform consumers about the environmental impact of different consumption options.

There are four main sections to this study. The first part, "Problem Analysis", includes an identification of stakeholders and a description of the research objective and questions. The development of the Food Environmental Impact (FEI) Model is covered in Chapter Two, which explains the rationale for certain methodological choices and the model's operation. The third section discusses how the model's results can be used to create a consumer communication tool. The fourth section, "sensitivity analyses," discusses how different methodological choices affect the model's results.

1 Problem Analysis

1.1 Problem Context

A food system encompasses all of the elements (such as environment, people, inputs, processes, infrastructures, institutions) and activities involved in the production, processing, distribution, preparation, and consumption of food, as well as the outcomes of these activities, including socio-economic and environmental outcomes (Meybeck & Gitz, 2017). The food sector is one of the leading causes of Land use change (and thus biodiversity loss), climate change, water scarcity/pollution, soil degradation, eutrophication, and acidification. The sector currently accounts for approximately 26% of global greenhouse gas emissions (CO_2, CH_4, N_2O), 70% of fresh water use, and more than a third of all potentially arable land. Even higher values are predicted if no mitigation measures are put in place (Batlle-Bayer et al., 2021) (Aleksandrowicz et al., 2016) (Ritchie & Roser, 2020). To comprehend, the food system has a significant environmental impact, and the need to move toward a more sustainable food system is critical. A sustainable food system is one that meets the nutritional needs of all people today and in the future while also protecting the planet's ecological systems (de Valk, Hollander, & Zijp, 2016).

Garnett identified three broad approaches to food sustainability in his study, namely efficiency-oriented, demand-constraint, and food system transformation. Food production and food producers are the focus of the efficiency-oriented perspective, which emphasizes the need to alter how food is produced by increasing the efficiency of food production processes. From a demand-constraint perspective, there is a need to alter unsustainable consumption patterns, which in turn influence food production, requiring a reduction in the consumption of high-impact foods. The third perspective, food system transformation, acknowledges the need for socio-economic structural change induced by policy makers to achieve social justice and environmental sustainability (Garnett, 2014). In this report the focus lies on the demand-constraint perspective.

Meybeck and Gitz argue that the effectiveness of the concept of sustainable consumption and production is based on the idea that in order to make systems more sustainable, attention must be paid to both the production and consumption sides, supply and demand. There are production choices and there are consumption choices; increasing sustainability is a function of both (Meybeck & Gitz, 2017).

In the transmission towards a more sustainable food system, educational institutions have played, and continues to play, an important role, as Fischer and Rieckmann have pointed out. Universities are considered a specific type of environment that can influence a range of health behaviors, including diet (Grech, Howse, & Boylan, 2020). Universities influence consumption in two ways. On the one hand, they can influence consumption by implementing interventions that encourage students and staff to consider more environmentally conscious consumption patterns. In the academic sphere, emphasis should be placed on raising public awareness of both global and local environmental issues, as well as on enhancing the required civic knowledge and skills regarding aspects of sustainable consumption. On the other hand, it is the educational institutions themselves where consumption takes place and they therefore can decide on what is offered on campus. They can reduce the environmental impact of the canteen menu by substituting ingredients with a higher environmental impact for those with a lower impact. (Fischer & Rieckmann, 2010) .

The problem in promoting more sustainable consumption lies in the fact that available options for sustainable consumption in the university canteen are mostly unknown to the consumer (Fischer & Rieckmann, 2010). Consumers are prone to underestimating food-related emissions, and as such environmental sustainability is not a criterion for their meal choices (Dai et al., 2020). However, consumer decision-making behavior can be altered when information is presented. Eco-labels are an important tool for providing customers with product information and for communicating environmentally friendly options (Ohlhausen & Langen, 2020).

In order to communicate the impacts of food choices to consumers and to identify high environmental impact ingredients, universities need to gain information on the quantified environmental impact of consumptions provided at the canteen. The Life Cycle Assessment (LCA) approach is a widely used method for quantifying the environmental impact of various types of food. The general LCA framework comprises four conceptual phases, namely (1) definition of purpose and scope, (2) life cycle inventory (LCI), (3) life cycle impact assessment (LCIA), and (4) interpretation. The LCI analysis quantifies energy use, material use, environmental emissions and waste in each life cycle stage (Dai et al., 2020). In the LCIA, depending on the goal of the research, indicators are selected in order to assess the environmental impact of different ingredients. Commonly selected impact indicators are GHG emissions, water use and land use. Food

LCA studies are usually conducted in three steps: the determination of the meal, the usual LCA procedure and a communication section where findings are communicated to the consumer and/or the results are used for policy making (Dai et al., 2020).

The Green Office's mission is to educate and inspire students and staff on how to be more environmentally aware and to show why this is important. They influence UoG's policies and operations to make them more sustainable. Part of this process is the sustainability development of the university canteen. The Green Office aims to reduce the environmental impact of the canteen menu. In order to communicate and inform the impacts of food choices to consumers and to provide suggestions on how to reduce the environmental impact of the canteen menu, The Green Office needs to gain information on the quantified environmental impact of food items provided at the canteen.

1.2 Stakeholder Analysis

The system is specified by identification of stakeholders. Based on the power and interest of the stakeholders, a Mendelow diagram is created which represents all stakeholders (see Figure 1).

- **Coordinator of The Green Office** - I. Maltagliati, Coordinator of The Green Office, is the problem owner and the commissioner of the project and aims to improve the sustainability of the UoG canteen menu. Hence, The Green Office seeks to get insights into the quantified environmental impact of ingredients served at the UoG canteens in order to identify high impact consumptions and opportunities for improvement to improve the sustainability of the menu. In addition, they are interested in having a communication tool to make students aware of the environmental impact of their lunch. As the project's commissioner, they are keenly interested in the project's outcome. Furthermore, because their operations are governed by the University of Groningen, they have a moderate influence over the project's outcome.
- **University of Groningen** - Because the UoG governs the Green Office's operations, it is the stakeholder with the most power. The sustainability of the University canteen menu is currently not a top priority, so it is given low/medium priority.
- **Beijk Catering** - Beijk is the current caterer of the UoG and provides the food served at the canteens. Because Beijk has few competitors in the province, they have a fair amount of influence over the project's outcome. Because the university cannot easily change caterers, their cooperation is critical to the outcome. The outcome of this project could be interesting for Beijk in case the caterer wants to improve their sustainability.
- **Canteen consumers** - The consumers of the UoG canteens can be divided in two subgroups, the staff and the students. These stakeholders play an important role in the project development because their behavior is going to influence the solution of the problem, being the ones that decide to consume the more sustainable option or not.

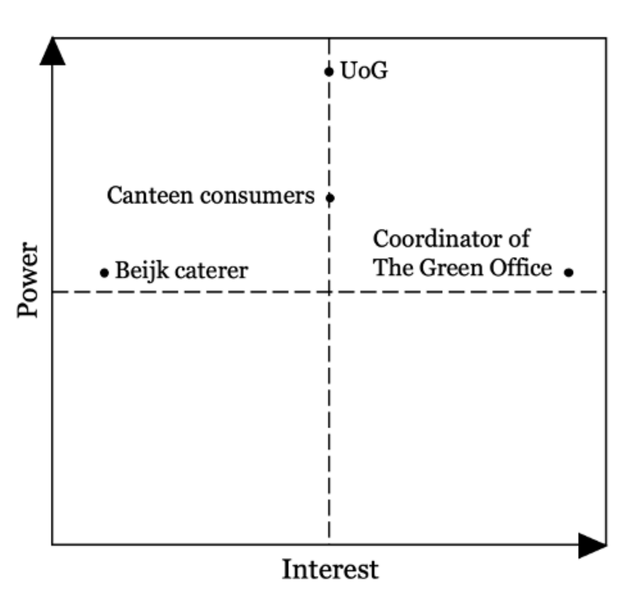

Figure 1: Stakeholder Analysis

1.3 Problem Statement

The problem statement is determined with the use of the Why-What analysis model (see Figure 2). The core problem in this study is the lack of quantification of the environmental impact of canteen's various consumption options. A quantification of the environmental impact is needed to be able to improve the overall sustainability. The problem statement is defined as:

The Green Office lacks information on the quantified environmental impacts of the university canteen's various consumption options. This information is required to make guidelines for reducing environmental impact and to design a communication tool that informs consumers about the environmental impact of their consumption choice and encourages them to choose more eco - friendly alternatives.

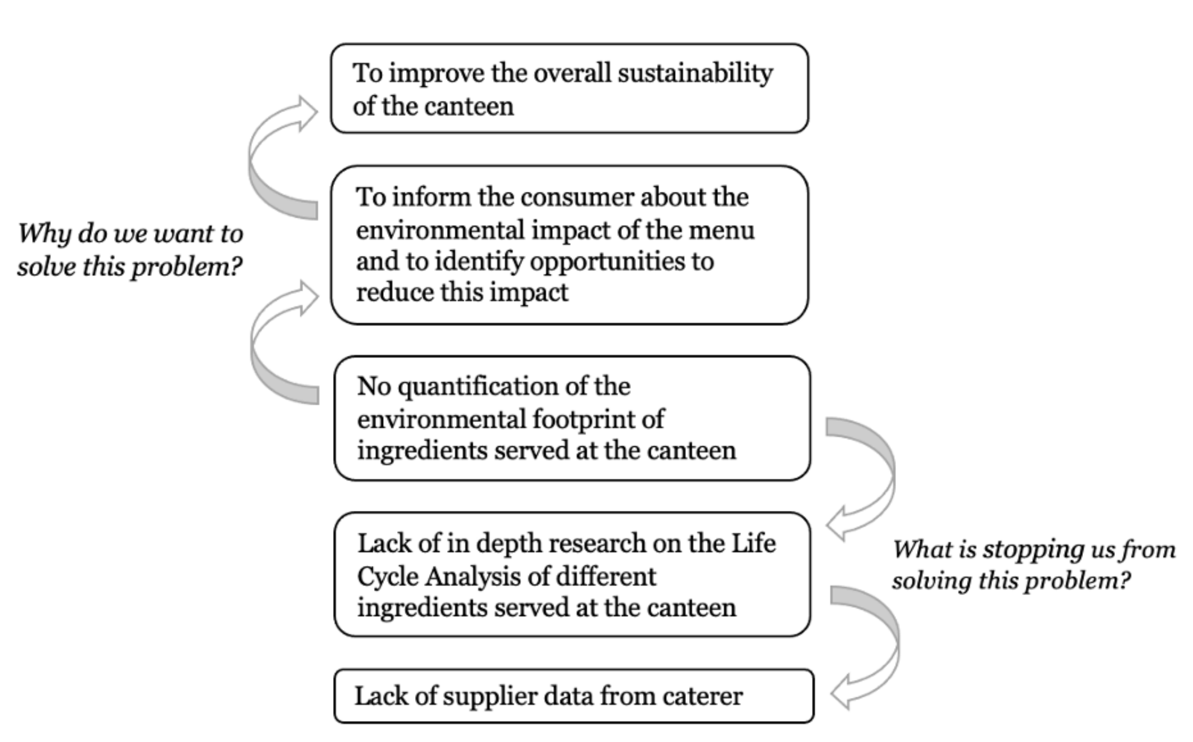

Figure 2: Why-What Analysis Model with core problem: lack of quantification

1.4 Goal Statement

The objective of this research is to increase The Green Office insights on the quantified environmental impact of food items provided at the university canteen, in order to identify high impact food items and ingredients, and to design a communication tool to inform the consumer about the environmental impact of their food choices within the time bound of three months.

In order to set out an effective research goals, the 'SMART' principle is to be followed (Doran, 1981). SMART stands for Specific, Measurable, Attainable, Relevant and Time-bound. From the problem statement we derive the knowledge goal to be "increase The Green Office insights on the quantified environmental impact of food items offered at the canteen", and the design goal of this research is to "design a communication tool to inform consumer about the environmental impact of their food choices. outlines how this research objective is SMART.

SMART objective:

- **Specific** - The environmental impact of food items offered in the canteen will be quantified. The results of the quantification will be used to design a communication tool to motivate students to opt for the more sustainable lunch option.
- **Measurable** - The aim is to increase The Green Office's information on the quantified environmental impacts of different consumption options provided at the canteen. The outcome of the research can be considered successful when this aim is achieved.
- **Achievable** - In the scientific literature, there are numerous studies that are similar. Furthermore, there are public LCA datasets and nutritional datasets available on the internet.
- **Relevant** - The Green Office and the UoG have set targets for the period 2021-2026 to improve the overall sustainability of the UoG, the canteen is part of this effort.
- **Time-bound** - 3 months

1.5 Research Questions

The main research question that aims to be answered is "how to improve the sustainability of the current UoG canteen menu?" In order to effectively answer this question, various sub-questions have been created which combined provide a sufficient answer to the main question. The sub-questions are as follows:

Research Question 1: What is the nutritional content of consumption options supplied in the UoG canteen in terms of protein in order to normalize the environmental impact indicators?

Research Question 2: What is the current quantified environmental impact of the consumptions supplied in the UoG canteen in terms of greenhouse gas emissions?

Research Question 3: What changes can be made to the canteen menu to reduce the environmental impact?

Research Question 4: What communication tool is most effective in informing consumers about the environmental impact of their food choice and encouraging them to choose the option that has the least environmental impact while also taking into account the consumer's values?

2 FEI Model

An Excel model, called Food Environmental Impact (FEI) Model, is developed to quantify the environmental impact of canteen items. The model's inputs are canteen item recipes, and its outputs are the environmental impact of these canteen items as measured by various impact indicators. The FEI Model is linked to an LCA database. This chapter elaborates on the selection of database, functional unit, and system boundary, as well as the development of the model.

2.1 Selection of Data Source

This study relies on secondary LCA data, as it is not feasible to generate primary LCA data due to a lack of time and supplier data. Since the results of this study strongly depend on the chosen data source, the choice of the selected data source must be well-considered. The study is bound to publicly available datasets, which are scarce.

In the following section, three public datasets are evaluated and compared to determine the most appropriate data source for this research. The first dataset is the Environmental Impacts of Food Data Explorer from the Our World in Data platform. This dataset is sourced from the largest meta-analysis of food systems to date by Poore and Nemecek (Poore & Nemecek, 2018) (Ritchie & Roser, 2020). The second dataset is from the National Institute of Public Health and Environment (RIVM) of the Netherlands. The RIVM studied the environmental impact of approximately 250 food products commonly consumed in the Netherlands (RIVM, 2021a). Thirdly, the SHARP-ID database, established by Wageningen University as an initiative to create a public database on the environmental impact of the food system in Europe (Mertens et al., 2019). Figure 3 summarizes differences between the three datasets regarding geographic location, system boundaries, selected functional units and impact categories, and the number of analyzed food products.

Database	Geographic Location	System Boundaries	Functional Unit(s)	Impact Catergories	# Products Analysed
Our Wourld in Data	Global level	cradle-to-gate	1 kg of food, 100 g of proteins per food, 1000 kcal per food	Carbon footprint, land use, water use, scarcity-weighted water use, water eutrophication	38
RIVM Database	Netherlands	cradle-to-gate, cradle-to-consumption	1 kg of food consumed by the Dutch consumer and sold by the Dutch market	Carbon footprint, land use, water use, terrestrial acidification, freshwater Eutrophication, Marine Eutrophication	238
SHARP-ID	Denmak, Czech Republic, Italy, France	cradle-to-consumption	1 kg of food consumed	Carbon footpint, land use	182

Figure 3: Comparison of methodology choices of three different data sources

In addition to comparing the methodological characteristics of the three different data sets, a comparison is made between the impact data of the same products from different data sources. The scope and functional unit must be equal to make a valid comparison. We examine the greenhouse gas impact data for six different products for comparison purposes, as both this impact indicator and six products appear in all three datasets.

First, the dataset of Our World in Data is compared to that of RIVM, with a cradle-to-gate scope and a functional unit of 1 kg of food (see figure 4). A cradle-to-gate scope includes animal feed production, crop/livestock production, manufacturing of inputs, primary production of fertilizers, food processing, transport, packaging, and retail. The second comparison is between the RIVM database and the SHARP-ID database, with a cradle-to-consumption scope and a functional unit of 1 kg of consumed food (see Figure 5). A cradle-to-consumption perspective includes all stages of a product's life cycle, from the cultivation of (feed) crop to consumption at home, i.e., including food preparation, storage, and food losses.

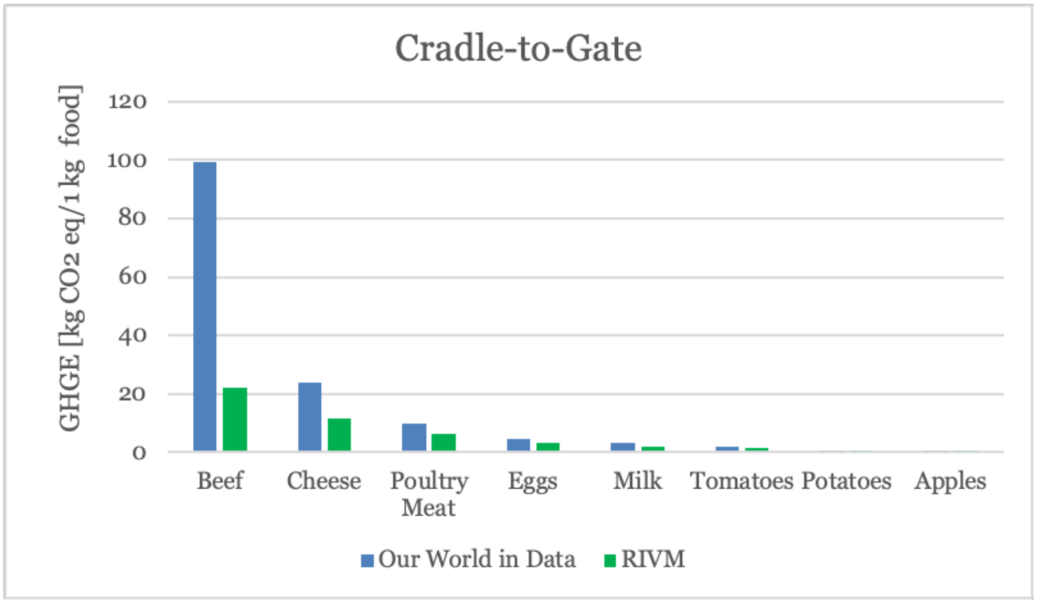

Figure 4: Comparison impact data between Our World in Data and RIVM database

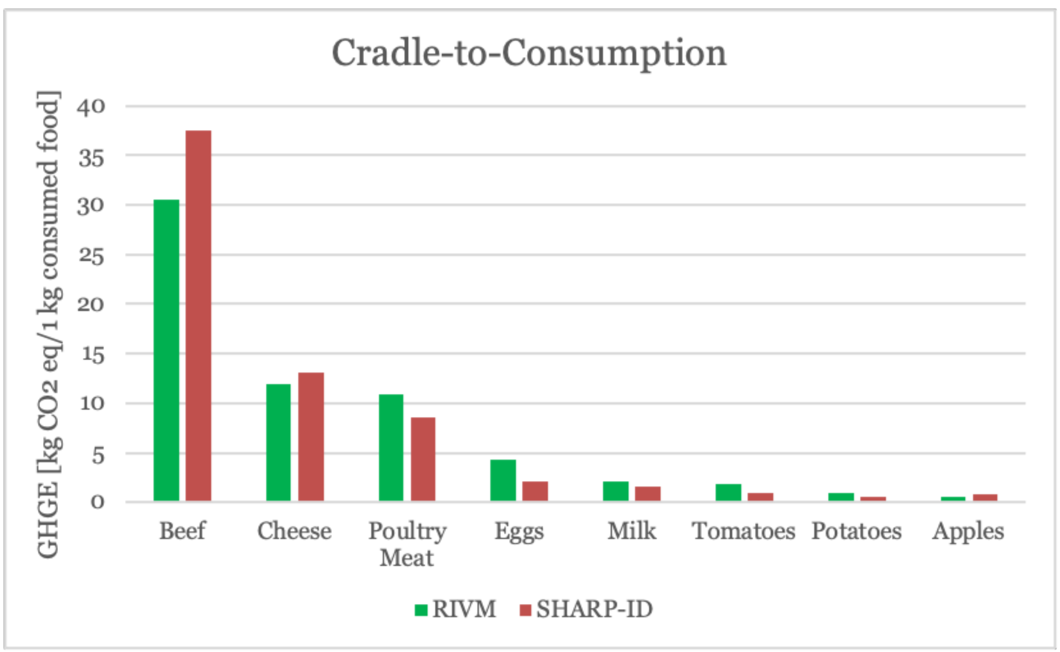

Figure 5: Comparison impact data of products of SHARP-ID and RIVM database

Significant differences can be observed when comparing the same product's impact data from different databases. This difference in impact data is due to several reasons, which will be explained in the next section.

Firstly, the difference can be explained by the different geographical perspectives of the datasets of the LCA studies. The values in the RIVM database are representative of products consumed or sold in the Netherlands. In contrast, Our World in Data values represents the global median values for 38 700 commercially viable farms in 119 countries. The impacts of the same product from different producers or countries can vary significantly due to specific production methods or regional differences related to production efficiency (Ritchie, 2020). Secondly, the remarkable significant difference in the impact of beef across the different data sources can be explained by the wide range of beef production systems, ranging from highly intensive to extremely extensive. In contrast, the impacts of poultry meat are more aligned between the datasets due to less variety of production systems (Nijdam, Rood, & Westhoek, 2012). As a result, the variety of different production methods for a given product can affect the impact of data differences. Furthermore, the disparity can be explained by the fact that, while the methodologies of the two compared data sources in both comparisons are mainly similar, some methodological details may differ. For example, the SHARP-ID database excludes food waste during consumption from the system scope, whereas the RIVM database includes food waste during consumption (Mertens et al., 2019) (RIVM, 2021a).

Despite the numerical differences, the broad conclusions drawn from the graphs for all three datasets are similar. In all three datasets, for example, meat has the highest impact, cheese has higher emissions than chicken, and chicken has a higher impact than eggs.

After comparing the three different data source options, the RIVM dataset was preferred for this study for several reasons. Firstly, the data source offers sufficient differentiation between foods, enabling good representations of consumption composed of multiple specific ingredients. Our World in Data contains product groups rather than specific products; therefore, quantifying the environmental impact of a consumption consisting of several different ingredients will be less accurate. For example, RIVM has impact data on specific cheese types, such as goat's cheese, mozzarella, and gouda cheese, whereas Our World in Data only has the average product group 'cheese'. Furthermore, the LCA database is focused on the Dutch market. It considers the origin of foods available on the Dutch market (i.e., using the appropriate ratio of domestic and imported products for each food and using data for appropriate production methods). The fact that the LCA data is specifically based on the Dutch market makes the impact calculations of food consumption more representative than if the impact indicators were based on a global average or an average of four other European countries. Another advantage is that the foods are labeled with a product-specific NEVO code. These NEVO codes enable to link the products with the Dutch Nutrient Database (NEVO), which consists of nutritional data of the food products, such as protein and energy content (RIVM, 2021b). This data is relevant when comparing the environmental impact of different recipes. The linked NEVO code also eases the building process of the FEI Model. A disclaimer of the RIVM LCA database is that the data is still under construction, is not reviewed by an external reviewer, and is therefore not ISO-certified. However, the data can be considered sufficiently reliable as it was generated by Blonk Consultants, a recognized company specialized in conducting LCA studies. In addition, the database is also used in a recent study by Wageningen University that uses the database for the same purposes (Vlek et al., 2022).

2.2 System Boundaries

An LCA study's system boundaries indicate which life cycle phases are included. The RIVM dataset contains two sets of data, each with a different system boundary: a "cradle-to-gate" and a "cradle-to-consumption" system. The dataset with a cradle-to-consumption system boundary is selected for the model. Since this system boundary option includes the stages of food preparation, food product sale, and food consumption, it results in more elaborated impact data, providing a more accurate representation of food items offered in a canteen. The following life cycle stages are included within the cradle-to-consumption boundary of the RIVM dataset:

- Primary food production, such as agricultural crops, livestock, and fish. This is calculated based on the country of origin. Several countries of origin are usually defined per food item to fit the market situation in the Netherlands.
- Post-harvest processing of primary products. A number of products are processed into food products in their country of origin, such as drying and peeling.
- Processing of primary products into food products. It is usually assumed that the processing of a food product takes place in the Netherlands.
- Food packaging. The type of packaging material was chosen based on current market offerings. Therefore, food products may appear twice in the dataset, for example, beans packaged in cans and beans packaged in glass. For food packaging, it is assumed that only primary packaging material is used, i.e., the last packaging in which the food is packed. It is also assumed that no recycled material is used. Discarded packaging is incinerated with energy recovery.
- Food product storage and distribution. The products are kept refrigerated or frozen in the distribution center until they are transported. Food losses during storage and distribution are included.
- Sales of food products. Food products, whether refrigerated or frozen, are stored and displayed for sale.
- Preparation of food items for consumption. This phase consists of three parts: the storage (whether refrigerated or frozen), the cutting, which leads to losses, and the 'cooking' of food. Waste disposal of packaging and cutting losses are also included in this phase of the life cycle.

- Consumption of food items. Not all prepared food is consumed. The impact of food losses to sewers, composting, and incineration are also considered at this stage.
- Transport is modeled through the chain (indicated in Figure 5 with black arrows), including sales on the Dutch market. Depending on the type of food and the country of origin, this can vary between air, water, road, and rail transport. Transport from the supermarket to the consumer (in this case, the caterer) was not included in the calculations (presented with red arrows in Figure 5).
- Food losses. Food is wasted at various points in the chain. These can be avoidable and non-avoidable food losses, such as losses at the distribution stage and cutting losses during preparation. Product group-specific percentages are used for avoidable food losses and product-specific percentages for cutting losses (RIVM, 2021a).

The stages included in the RIVM's cradle-to-gate scope are focused on consumption at home rather than food consumed away from home, such as in a canteen setting. The distinction between the two perspectives is insignificant, as they both consist of the same life cycle phases. However, it makes more sense to reverse the sales and food preparation phases for catering purposes, and this change will not affect the impact data (see Figure 6). The RIVM's cradle-to-consumption scope dataset is also used in a study on food transparency from the University of Wageningen for the same purposes (Vlek et al., 2022).

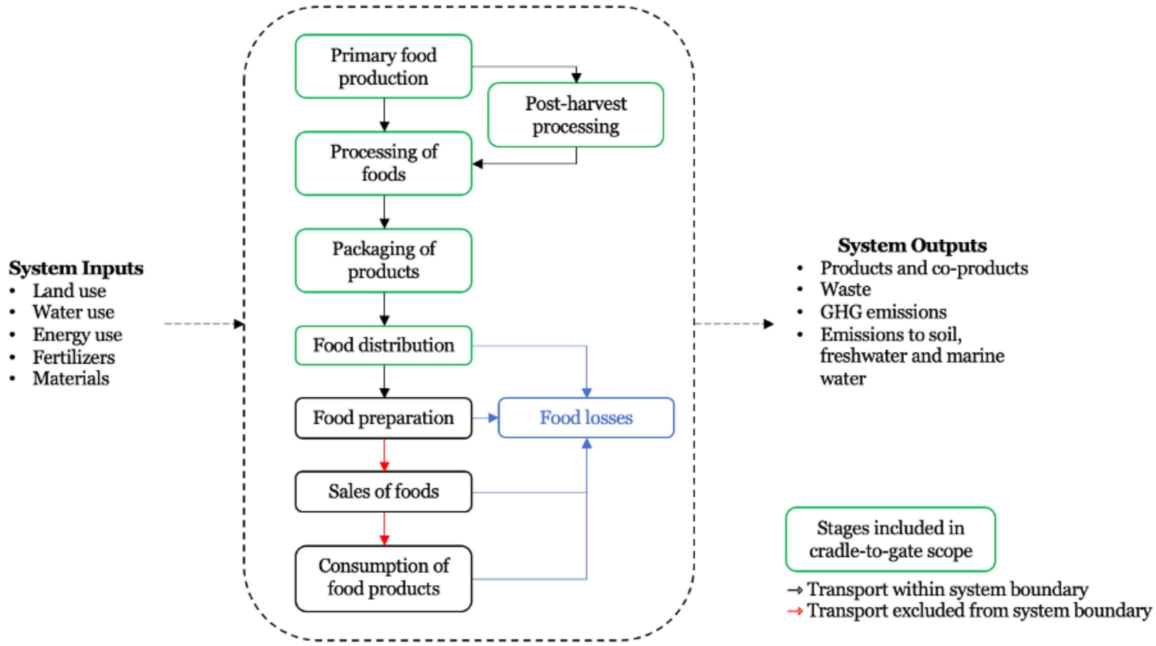

Figure 6: Schematic overview of the system of cradle-to-consumption system

2.3 Functional Unit

An LCA is a comparative approach structured around a functional unit (FU). The FU is a reference unit and a basis for possible product comparisons. The FU defines a measurement unit of the function that describes the purpose of the product studied in an LCA. In performing an LCA, all subsequent analyses are then undertaken, and the results are presented relative to that FU. The choice of FU depends on the target group and research objectives (McLaren et al., 2021).

In this research, the target group is the canteen consumer, and the goal is to educate them about the environmental impact of their food choices. A mass-based FU was chosen in this research, namely "1 kg of food consumed by the Dutch consumer and sold through the Dutch market"; as this FU is used in the selected RIVM dataset. The environmental impact related to mass-based FU can easily be converted into a meal-based FU, which is useful, for example, when comparing the environmental impact of different sandwich options.

The vast majority of food products LCAs in literature uses mass/volume-based FU. The downside of using a mass/volume-based FU for comparisons is that it does not express food functionality. If providing nutrients to the body is considered to be the primary function of food, it is not represented in a mass/volume-based FU. However, The Food and Agriculture Organization of the United Nations (FAO) considers mass- and meal-based FUs appropriate when the interested party are consumers, and the goal is to educate people about the environmental impact of their food choices.(McLaren et al., 2021) In addition, similar studies in literature have also selected mass-based and meal-based FUs (Volanti et al., 2022) (Grech et al., 2020) (Dai et al., 2020).

The functional unit used in the model is either mass-based or recipe-based, depending on the input configurations. However, this implies that recipes and ingredients with different nutritional values are directly compared. This could lead to different results than if a nutritional functional unit, such as protein or kcal content, had been chosen (De Laurentiis, Hunt, Lee, & Rogers, 2019). In order to examine how this methodological choice affects the results, a sensitivity analysis comparing results calculated using different functional units, such as protein and energy content, will be carried out in the "Sensitivity Analyses" section of this report.

2.4 Impact Categories

Indicators are required to quantify the environmental sustainability of our food consumption. The United Nations Environment Programme (UNEP) research presents a schematic overview of indicators related to the food system's environmental impact (see Figure 6). Among the indicators, a distinction is made between environmental impacts and natural resources, both due to human activity. In many cases, food system activities significantly degrade natural resources while contributing to climate change and local and regional pollution (Hajer, Westhoek, Ingram, Van Berkum, & Özay, 2016).

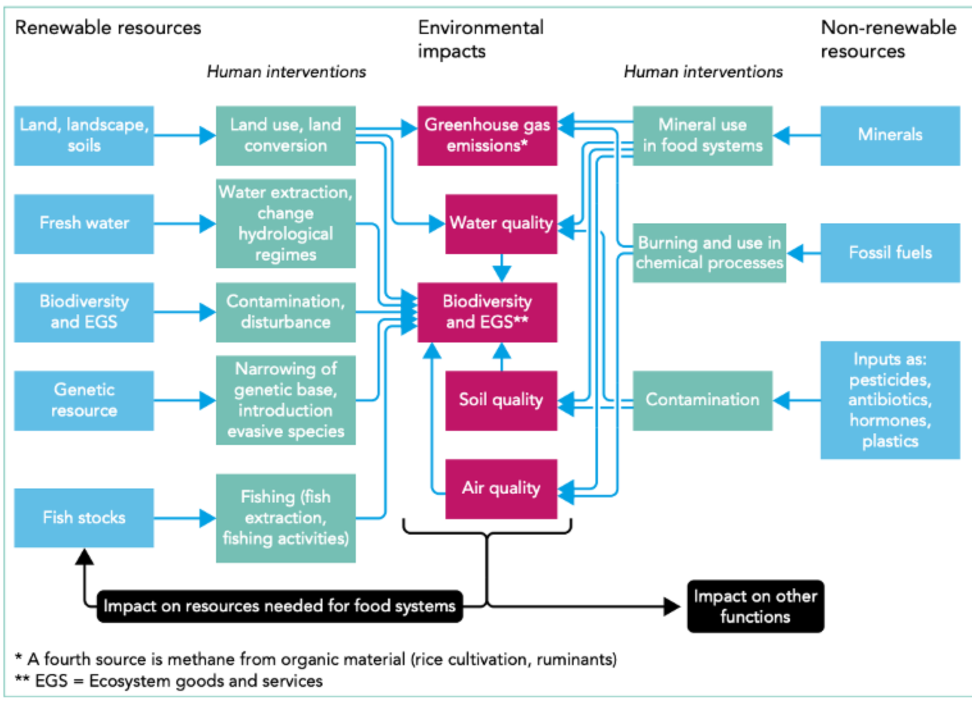

Figure 7: Schematic overview of relations between resource use and environmental impacts related to food system activities (Hajer et al., 2016)

Food system activities require a variety of natural resources. There are two types of natural resources: renewable and non-renewable. Land, water, biodiversity, and ecosystem goods and services are all important renewable resources for food systems. After exploitation, renewable resources can return to their natural stock levels through natural processes of growth or replenishment, assuming they have not reached a critical point where regeneration is extremely slow or impossible. Minerals and fossil fuels are essential non-renewable resources used in food systems. The activities of the food system have a significant impact on the environment. Many of these consequences are interconnected to the utilization of natural resources. The use of fossil fuels, for example, results in CO_2 emissions, whereas minerals usually result in nutrient emissions into ground and surface water (Hajer et al., 2016).

The optimum would be to quantify the entire set of impact indicators; however, this research is bound by the availability of data. As a result, this research focuses on the environmental impact and resource use indicators for which data is available in the RIVM database, namely greenhouse gas emissions, soil quality via acidification, freshwater, and marine water quality via eutrophication, land use, and water use. The following definitions of the environmental impact indicators are used in the model.

Environmental impacts:

- **Greenhouse gas emission (global warming)** - Human-caused GHG emissions result in increased global warming (climate change); the amount of GHG emitted is widely used as a metric of climate change. CO_2, CH_4, and N_2O are the most significant emissions in the food life cycle. All emissions are recalculated into CO_2 equivalents in this study.

- **Soil quality via acidification** - This is a measure of the change in soil acidity caused by human-caused inorganic material deposition in the atmosphere. All emissions that contribute to acidification during a product's life cycle, such as sulfates, nitrates, and phosphates, are included. Acidification is measured in the unit kilograms SO_2 equivalent.

- **Freshwater quality via eutrophication** - This is a measure of the amount of nutrients added to freshwater environments due to human activity. All emissions that contribute to eutrophication during a product's life cycle are considered. Since these emissions mainly consist of phosphate compounds, eutrophication is measured in kilograms of phosphorus equivalent.

- **Marine water quality via eutrophication** - This is a measure of the amount of nutrients added to marine water environments due to human activity. All emissions that contribute to eutrophication during a product's life cycle are considered. Since these emissions mainly consist of nitrogen, eutrophication is measured in kilograms of nitrogen equivalent (RIVM, 2021a).

Use of resources:

- **Water use** - This is an indicator for freshwater consumption as a result of human activity. It concerns irrigation water during the cultivation of crops and is expressed in m^3 of water.

- **Land use** - Land use is defined as the land surface that is required per year for the total supply chain of food products. Two mechanisms are distinguished: 1) the use of a specific area of agricultural land, and 2) the transformation of a specific area of (natural) land to make it appropriate for agricultural and food production processes. Both mechanisms are included in one indicator and expressed in m^2 (RIVM, 2021a).

These six environmental impact indicators capture a substantial part of the food system's environmental impact. Agricultural food production is responsible for more than 60% of terrestrial biodiversity loss. Biodiversity loss is strongly correlated with land use due to the conversion of natural habitats into agricultural land, which has significantly less biodiversity than natural land. Only 15-20% of the total nitrogen and phosphorous input via fertilizers is contained in the food that ends up on the consumer's plate, which means that a significant amount of nutrients is lost to the environment. Phosphate and nitrogen losses and pesticide emissions lower the biodiversity in freshwater and the coastal marine environment. The loss of soil quality due to acidification, as well as the loss of fresh and marine water quality due to eutrophication, is a significant issue in the Netherlands. Critical nutrient loads, particularly nitrogen, are continuously exceeded (Zijp et al., 2017). Regarding freshwater use for global food production, agricultural irrigation accounts for up to 70% of total freshwater use (Ohlhausen & Langen, 2020), with 15–35 percent considered unsustainable. Furthermore, food consumption and production account for roughly 26% of total global greenhouse gas emissions (Ritchie & Roser, 2020), primarily due to manure (CH4 and N2O) and energy use across the food system (Zijp et al., 2017).

2.5 Development FEI Model

The FEI Model, created in Excel, calculates the environmental impact and the nutritional value of ingredients/recipes. The model's interface is linked to two datasets: the RIVM Dataset, which contains information on the environmental impact of food products consumed in the Netherlands, and the NEVO Dataset, which contains information on the nutritional value of food products. The input interface consists of three recipe input tables where ingredients and quantities can be entered (see Figure 8).

Recipe 1

Ingredient	NEVO code	Quantity [g]
Hummus naturel	3207	40
Tomaat, rauw	2734	25
Broodje wit, hard	2795	100
Total		165

Recipe 2

Ingredient	NEVO code	Quantity [g]
Achterham	784	40
Tomaat, rauw	2734	25
Broodje wit, hard	2795	100
Total		165

Recipe 3

Ingredient	NEVO code	Quantity [g]
Oude kaas, 48+	883	40
Tomaat, rauw	2734	25
Broodje wit, hard	2795	100
Total		165

Figure 8: Input tables of recipes for ingredients and quantity of ingredients in grams

Ingredients can be selected out of the 238 available products in the RIVM Database using the search list (See Figure 9). When a food ingredient is selected from this list, the model will automatically search for its specific NEVO code. This NEVO code is presented in both linked datasets and serves as a link between the two datasets.

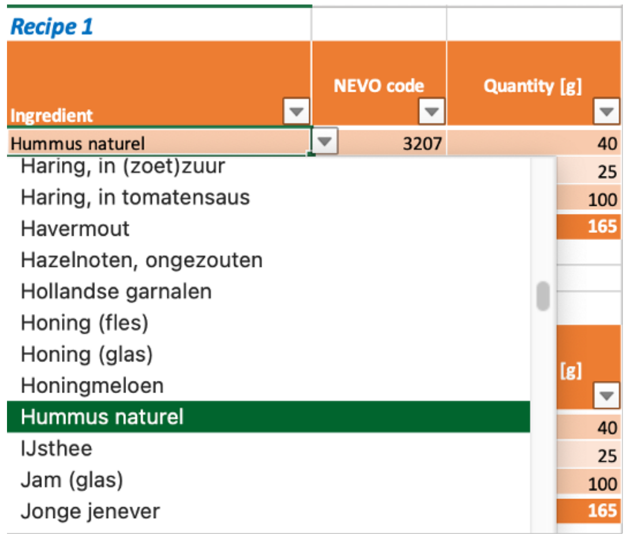

Figure 9: Selection of ingredients from using the search list

The second entry to be filled in is the quantity of the ingredient in grams. When the ingredient and quantity are filled in, the model automatically calculates the ingredient's corresponding impact indicator and nutritional values. The model retrieves the required data linked to the NEVO code from the two datasets, multiplies the matching data by the given quantity in grams, and gives the corresponding values of kilocalories (in kcal), protein content (in g), global warming (in kg CO2 eq), land acidification (in kg SO2 eq), freshwater eutrophication (in kg P eq), marine eutrophication (in kg N eq), land use (in m^2*year) and water use (in m^3).

The model automatically sums up the data in each recipe's 'Total' row to obtain the recipe's total nutritional content and environmental impacts. The total nutritional values are convenient information when different recipes are compared. When comparing different recipes, it is critical to consider the extent to which a food item provides a good source of nutrition.The color dot in the total row indicates the relative impact within the impact category compared to the other recipes. The green dot indicates that the recipe has the lowest impact within that impact category, and the red dot indicates that the recipe has the highest impact. The yellow dot indicates that the recipe has an intermediate impact compared to the other recipes. For example, recipe 1 has the lowest impact within the global warming category, recipe 2 has an intermediate impact, and recipe 3 has the highest impact (see Figure 10).

Energy [kcal]	Protein [g]	Global Warming [kg CO2 eq]	Terrestrial Acidification [kg SO2 eq]	Freshwater Eutrophication [kg P eq]	Marine Eutrophication [kg N eq]	Land Use [m2 * year crop eq]	Water Use [m3]
129	3,1	0,256	0,0004	0,000014	0,000213	0,414	0,0044
6	0,2	0,045	0,0000	0,000001	0,000002	0,001	0,0025
277	10,0	0,119	0,0007	0,000015	0,000280	0,111	0,0021
412	13,3	0,420	0,0011	0,000029	0,000496	0,526	0,0091

Energy [kcal]	Protein [g]	Global Warming [kg CO2 eq]	Terrestrial Acidification [kg SO2 eq]	Freshwater Eutrophication [kg P eq]	Marine Eutrophication [kg N eq]	Land Use [m2 * year crop eq]	Water Use [m3]
54	7,2	0,433	0,0043	0,000038	0,000545	0,334	0,0042
6	0,2	0,045	0,0000	0,000001	0,000002	0,001	0,0025
277	10,0	0,119	0,0007	0,000015	0,000280	0,111	0,0021
336	17,4	0,597	0,0051	0,000053	0,000827	0,446	0,0088

energy [kcal]	Protein [g]	Global Warming [kg CO2 eq]	Terrestrial Acidification [kg SO2 eq]	Freshwater Eutrophication [kg P eq]	Marine Eutrophication [kg N eq]	Land Use [m2 * year crop eq]	Water Use [m3]
153	9,7	0,524	0,0074	0,000015	0,001044	0,214	0,0042
6	0,2	0,045	0,0000	0,000001	0,000002	0,001	0,0025
277	10,0	0,119	0,0007	0,000015	0,000280	0,111	0,0021
436	19,9	0,688	0,0082	0,000031	0,001326	0,326	0,0088

Figure 10: Environmental impact data and nutritional data of ingredients and recipes

The 'Output' sheet of the FEI Model displays pie diagrams of each impact indicator for all three recipes. For example, the pie diagrams of the three recipes for the impact indicator Global Warming are shown in Figure 11. The pie chart provides a good overview of the "hotspot" ingredients of the recipe. The impact of an ingredient is, of course, proportional to the amount entered, and this should be considered when comparing different recipes. The pie charts can display percentages as well as values. Both percentages and values can be read from the pie charts.

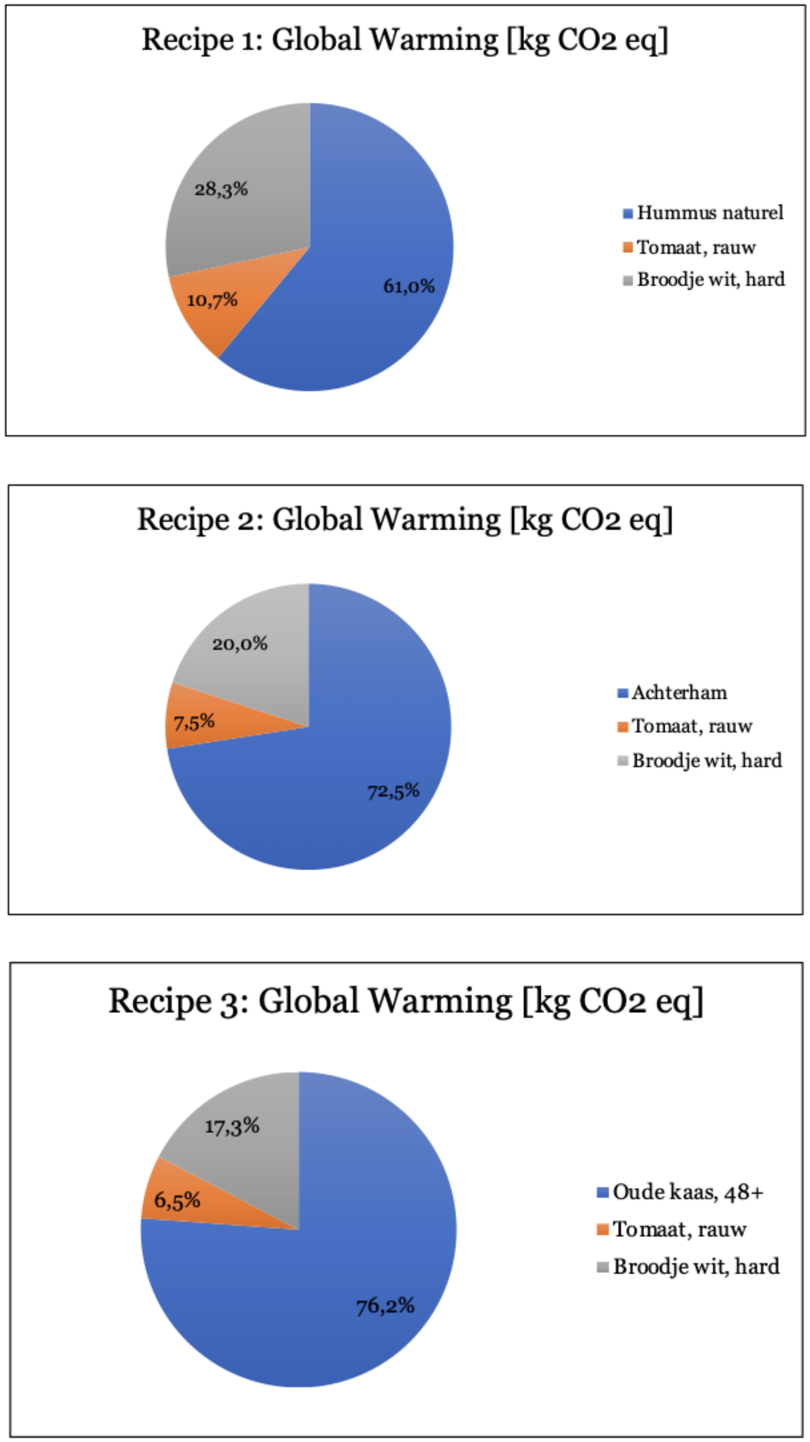

Figure 11: Pie charts of Global Warming impact of three recipes

The recipe input tables provide two options for comparison. First, different recipes can be compared, as illustrated in Figure 11. Secondly, individual ingredients can be compared by filling out the recipe input table with the selected ingredients for comparison and using the same amount in grams for each. Figure 11 shows a pie chart of the global warming impact, including three ingredients (hummus, cheese, and ham). A quantity of 100 grams was entered for each of the three ingredients.

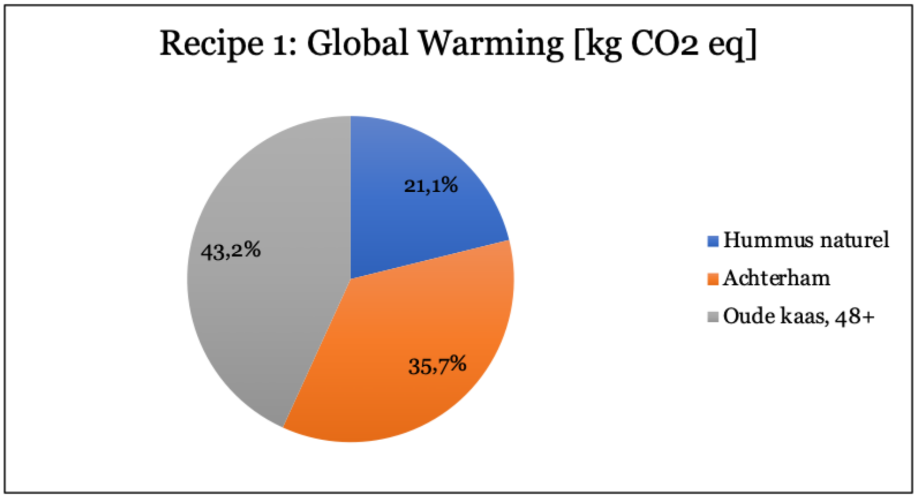

Figure 12: Pie chart of Global Warming impact for comparison of three individual ingredients with a quantity of 100 grams

3 Communication Tool

This chapter describes how the results of the FEI model on food's environmental impact can be communicated to consumers. The first section will briefly overview food labels discussed in the literature. Subsequently, the environmental impact of nine different types of sandwiches is calculated, with the results being used to create a communication tool to inform consumers of the impact of their food choices. The environmental impacts of the sandwiches are evaluated qualitatively in the final section.

3.1 Literature Review on Food Labels

Dietary change is considered one of the key actions in reducing the food system's environmental impact. One way to motivate food consumption changes and inform the consumer is through environmental food labels. Environmental food labels can help consumers compare and within food product types and make more sustainable and environmentally-conscious decisions (Osman & Thornton, 2019) . The format of the food label significantly influences the effectiveness of environmental food labels (Muller, Lacroix, & Ruffieux, 2019) (Vandenbroele, Vermeir, Geuens, Slabbinck, & Van Kerckhove, 2020).

Muller tested the effectiveness of three different environmental food label formats in his research, namely: single-traffic lights presenting one environmental impact category, multiple traffic lights presenting multiple environmental impact categories, and the kilometric format, indicating the greenhouse gas emission for each product by indicating the equivalent number of kilometers driven by an average car (see Figure 13). A traffic light label is an evaluative food label, where red indicates a high environmental impact, yellow a medium environmental impact, and green a low environmental impact. The single-traffic light only presented the greenhouse emission of the product, whereas the multi-traffic light label also presented the acidification and marine eutrophication of the product.

All three formats have led consumers to purchase more environmentally friendly food items. However, the multi-impact label format appeared to be the one that generated the most significant decrease in the environmental impact, although simplicity usually improves label effectiveness. For example, this is the case for nutritional labeling: a single-criteria label shows more effectiveness than a multi-criteria label. The main reason for these contradictory results is that the nutritional criteria (sugar, fat, and salt) are uncorrelated. However, GHG, marine eutrophication, and acidification are strongly correlated. The result is that multi-criteria nutritional labels feature different colors, while a correlated multi-criteria environmental label features the same three colors. Consequently, multi-criteria nutritional labels force consumers to make trade-offs, while multi-criteria environmental ones generate more saliency. Furthermore, the research shows that the label with the impact expressed in kilometers driven by a car was the least effective. This finding shows that a simple color-coded logo is superior to a more informative one (Muller et al., 2019).

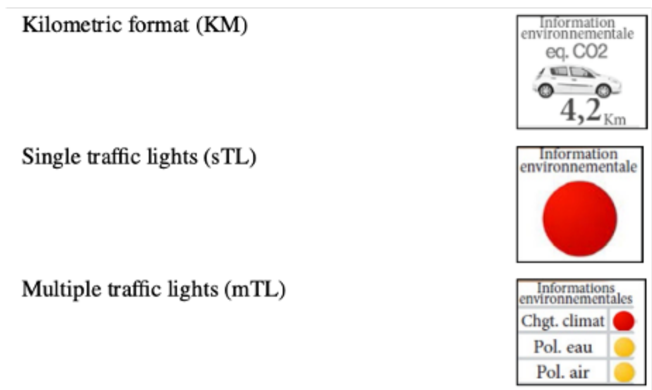

Figure 13: Three different environmental food label formats tested in Muller's research

The study by (Vandenbroele et al., 2020) also favored an evaluative food label over a more informative label, as it is easier for consumers to interpret and understand. In addition, the effectiveness of traffic light labeling is mentioned in this study. It is hypothesized that red can act as a signal to stop consumption because traffic light labeling is based on our socially learned associations, where green means safety and red means danger.

Similarly, Vlaminck's research argues that a standardized color scale is more accessible than informative data because informative data is more difficult for non-experts to assess. When informative data is presented to the consumer, for example, the carbon footprint expressed in miles driven by an average car, she/he has to compare products to indicate whether the product has a relatively low or high environmental impact. In contrast, a standardized color scale, such as red for high impact, yellow for medium impact, and green for low impact, gives the consumer an immediate indication of the relative environmental impact of the product. Additionally, Vlaminck also supports a multi-criteria environmental food label that considers the interaction of multiple environmental impacts (Vlaeminck, Jiang, & Vranken, 2014).

3.2 Correlation between Impact Categories

According to the literature review presented in the previous section, the traffic light environmental food label is considered an effective method to inform consumers about the environmental impact of their food choices as it is easy to interpret. When a consumer is exposed to a traffic-light label with three different colors representing three different environmental effects, interpreting the label becomes more complex, reducing the label's effectiveness. The multiple-criteria label is only more effective than a single-criteria label when there is a strong positive correlation between the presented impact categories.

The environmental impact data set used in the FEI model was examined to determine whether correlations existed between the six impact categories. The correlation between the environmental impact indicators of the 238 products in the FEI model was determined using Excel's built-in correlation function. This function computes the Pearson population correlation coefficient, which measures the strength of correlation between two variables. The Pearson population correlation coefficient, ρ_{XY}, is calculated according to the following formula (Bhandari, 2022):

$$\rho_{XY} = \frac{cov(X,Y)}{\sigma_X \sigma_Y}$$

In the case of determination of the Pearson population correlation coefficient (ρ_{XY}) between global warming and terrestrial acidification, X denotes the population of 238 values for global warming impact, and Y denotes the population of 238 values for terrestrial acidification. The covariance (cov) is the degree to which the two variables change together. And σ_X denotes the population standard deviation of X, and σ_Y denotes the population standard deviation of Y.

The obtained Pearson population correlation coefficients (ρ_{XY}) between the impact indicators are summarized in Figure 14, with dark red denoting a strong correlation and light red denoting a weaker correlation. The results show a strong positive correlation between global warming, terrestrial acidification, and marine eutrophication, indicated by the darker red color. This strong correlation implies that if a product has a high global warming impact, it is likely to have a high impact on terrestrial acidification and marine eutrophication as well. Categorizing the 238 products into green for low impact, yellow for medium impact, and red for high impact would mean that there is a high likeliness that if the product is labeled red in global warming impact category, the likeliness that the product is also labeled red in the impact category of terrestrial acidification and marine eutrophication is high. This finding is in line with the findings presented in the research of (Muller et al., 2019).

	Global Warming	*Terrestrial Acidification*	*Freshwater Eutrophication*	*Marine Eutrophication*	*Land Use*	*Water Use*
Global Warming	1					
Terrestrial Acidification	0,913	1				
Freshwater Eutrophication	0,468	0,361	1			
Marine Eutrophication	0,876	0,985	0,379	1		
Land Use	0,717	0,697	0,544	0,730	1	
Water Use	0,013	0,021	0,275	0,075	0,292	1

Figure 14: Matrix presenting the Pearson population correlation coefficient, ρ_{XY}, between the six impact indicators

Given the strong positive correlation determined in the previous section, a multi-traffic light label is a viable option for informing consumers about the impact of their food choices on global warming, terrestrial acidification, and marine eutrophication. On the other hand, water consumption has a relatively weak correlation with the other impact categories. This weak correlation means that the color label for the impact indicator will most likely be different from the color labels for the other impact indicators. The same can be said for the category of freshwater impact. Land use shows a stronger correlation than water consumption and freshwater eutrophication; however not as significant as can be observed between global warming, terrestrial acidification, and marine eutrophication.

3.3 Environmental Impact Sandwiches

The first step in creating a communication tool is deciding which products will have their environmental impact communicated to consumers. Following that, the recipes for these products must be specified, including the ingredients used and their quantities. The various environmental impacts of the products can then be quantified using the FEI Model. Consequently, the resulting impact data can be transformed into easily understandable information for consumers, such as a traffic-light label.

In this section, the environmental impact of 9 types of sandwiches will be quantified. The recipes for the nine sandwiches can be observed in Figure 15. The sandwich selection is inspired by what is offered at the canteens of the University of Groningen. For all sandwiches, the amount of the main ingredient has been set to 40 grams, and the remaining ingredients are standardized to allow for a proper comparison. Ingredient 3 differs between cucumber and tomato; because this ingredient is often dependent on the main ingredient; for example, a mozzarella sandwich is often served with tomato and not with cucumber. Both vegetable toppings have approximately the same nutritional value and environmental impact and, therefore, will not significantly affect the difference in environmental impact between the sandwiches.

Sandwich	Ingredient 1 (main)	Ingredient 2 (bread)	Ingredient 3 (topping 1)	Ingredient 4 (topping 2)
1	40 g Filet American	90 g White	20 g Cucumber	5 g Lettuce
2	40 g Ham	90 g White	20 g Cucumber	5 g Lettuce
3	40 g Cheese	90 g White	20 g Tomato	5 g Lettuce
4	40 g Humus	90 g White	20 g Tomato	5 g Lettuce
5	40 g Salmon	90 g White	20 g Cucumber	5 g Lettuce
6	40 g Beef	90 g White	20 g Cucumber	5 g Lettuce
7	40 g Mozzarella	90 g White	20 g Tomato	5 g Lettuce
8	40 g Chicken filet	90 g White	20 g Cucumber	5 g Lettuce
9	40 g Goat cheese	90 g White	20 g Cucumber	5 g Lettuce

Figure 15: Recipes of Sandwiches

The nine sandwiches' environmental impact and nutritional values are calculated by implementing the recipes in the FEI Model; a summary of the results can be found in Figure 16. Each impact indicator value is labeled with a red, yellow, or green dot. The dot is green when a sandwich belongs to the lowest impact, one-third of all sandwiches in the impact category. The dot is yellow when the sandwich belongs to the middle third and red when it belongs to the highest impact one-third. The strong correlation between global warming, terrestrial acidification, and marine eutrophication can be observed when looking at the color labels associated with the impact values.

Sandwich	GWP [kg CO2 eq]	TA [kg SO2 eq]	FE [kg P eq]	ME [kg N eq]	LU [m2*year]	WU [m3]
1 (Filet American)	0,855	0,0123	4,30E-05	2,23E-03	0,537	0,0110
2 (Ham)	0,581	0,0050	5,20E-05	8,05E-04	0,437	0,0081
3 (Cheese)	0,670	0,0081	3,00E-05	1,30E-03	0,317	0,0083
4 (Humus)	0,403	0,0011	2,80E-05	4,74E-04	0,517	0,0090
5 (Salmon)	0,413	0,0013	3,30E-05	4,20E-04	0,189	0,0060
6 (beef)	1,369	0,0221	6,00E-05	3,82E-03	0,721	0,0140
7 (mozzarella)	0,485	0,0055	2,40E-05	9,31E-04	0,241	0,0070
8 (Chicken)	0,583	0,0044	5,10E-05	5,94E-04	0,401	0,0100
9 (Goat Cheese)	0,488	0,0050	4,00E-05	9,41E-04	0,350	0,0090

Figure 16: The results on environmental impacts and nutritional values of the sandwiches generated by the FEI Model

3.4 Selection of Food Label

The traffic light format is chosen for the design of the communication tool based on findings in the literature supporting the effectiveness of this label format. Since the FEI model generates data of six impact categories, there are several options for the traffic-light label, namely, a single traffic light (STL) label, presenting only one impact category, a correlated multi-traffic light label (MTL), presenting global warming potential, terrestrial acidification and marine eutrophication, and a multi-traffic light label containing all six impact categories. The three food labels are developed based on the results derived in the previous section and can be observed in Figures 17, 18, and 19. Terrestrial acidification is an impact indicator for soil quality; marine eutrophication is an impact indicator for marine water quality, and freshwater eutrophication is for freshwater quality (Hajer et al., 2016). Soil, marine water, and freshwater quality are easier to understand for the consumer and are therefore used for the food label.

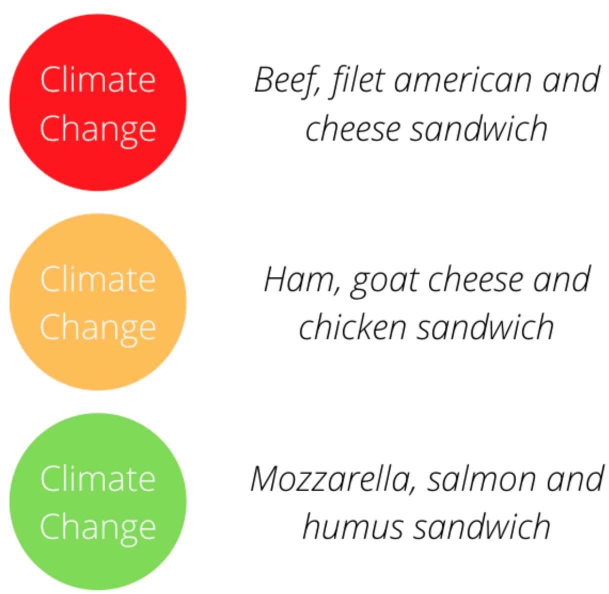

Figure 17: Example of STL food label for the nine sandwiches

Figure 18: Example of the correlated MTL food label for the nine sandwiches

Figure 19: Example of the TL food label presenting all six impact indicators

To maintain the effectiveness of the environmental food label, it should be simple and clear (Gadema & Oglethorpe, 2011). The issue of assessing a food item's environmental impact is complex, and communicating about it through an environmental food label demands simplification. Indicators are a helpful way to simplify how the environmental system is described. Indicators can provide understandable and readily interpretable information, which can be the basis for informed choices and effective food labels. These indicators need to reflect the crucial factors that cause diets to pressure on the environment, but there is always a trade-off between completeness and simplicity (van Dooren, Aiking, & Vellinga, 2018).

The trade-offs between simplicity and completeness of the three traffic-light food label options are schematically placed in figure 20. Using a STL food label simplifies the consumer's interpretation of the label but does not provide a complete picture of the various environmental burdens associated with the food choice. Due to existing trade-offs between impact categories, it becomes more difficult for the consumer to interpret which sandwich is more environmentally friendly when all six impact indicators are included in the environmental food label sandwiches. A chicken sandwich, for example, receives a red rating for freshwater eutrophication and water use, a yellow rating for global warming potential and land use, and a green rating for terrestrial acidification and marine eutrophication. When these color scores are displayed, the consumer becomes confused, reducing the label's effectiveness. The correlated mTL food label, which includes global warming potential, land acidification, and marine eutrophication, provides a more complete picture of food's environmental impacts than a STL label. However, it is still relatively easy to interpret because the existing correlations lead to more uniformity among the impact indicators.

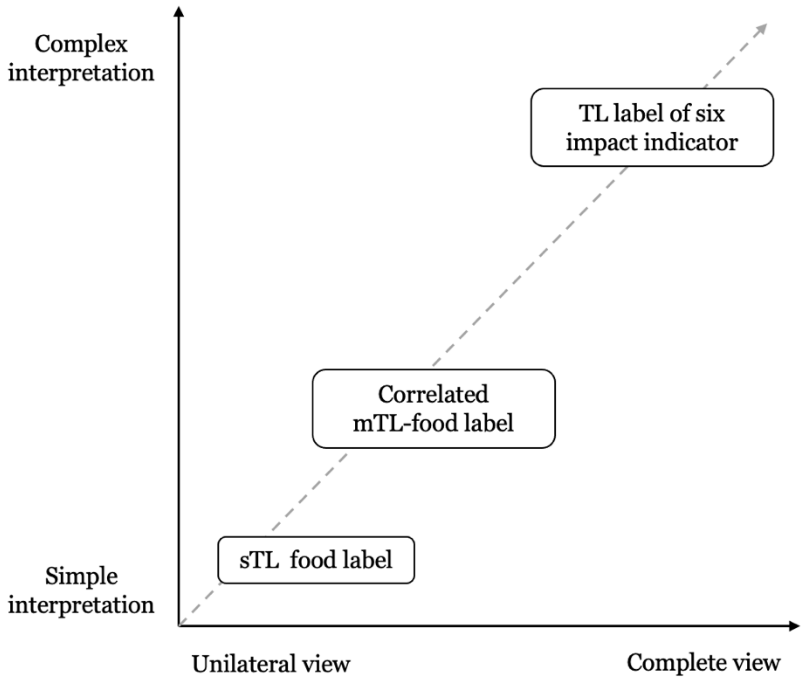

Figure 20: Trade-offs between simplicity and completeness of the three label formats

Of these three options within the traffic light label format, the correlated MTL food label is considered the best possible label format. Due to the correlations between climate change, land acidification, and marine eutrophication, the food label provides a relatively complete picture of the different environmental burdens without confusing consumers with trade-offs between different impact categories. Moreover, in Muller's study, the correlated MTL label was considered more effective than the STL food label (Muller et al., 2019).

3.5 Discussion of Results

Figure 18 demonstrates the nine sandwiches' multi-criteria traffic light environmental food labels. From the multi-criteria environmental food, labels can be concluded that the sandwiches containing beef, filet american and cheese have the highest impact on the environment and are considered to be the worst choice given the environmental impact. On the other hand, the sandwich containing humus or salmon is considered the best option. The chicken sandwich has a low environmental impact compared to the other types of meat. Hence, if the consumer has to choose between the meat sandwiches, chicken would appear to be the best option and steak the worst, given the environmental impact. When looking at the sandwiches containing types of cheese, regular cheese has the most significant impact on the environment, whereas mozzarella has the lowest impact. Conclusions are more easily drawn when looking at these impact indicators. Few trade-offs between the impact categories can be observed due to the high correlation between the three impact indicators. However, these three impact indicators do not give a complete picture of the environmental impact, as they do not cover land use, water use, and freshwater eutrophication.

When all six impact indicators are included in the environmental assessment of the sandwiches, determining which sandwich has the lowest impact becomes more complex as trade-offs between the different impact categories become more apparent (see figure 19). For example, the cheese sandwich scores red on the global warming potential, terrestrial acidification, and marine eutrophication but green on land use and freshwater eutrophication, and the sandwich with humus scores green for almost all impact indicators but requires a relatively high amount of water since it scores red on water use. However, this does not apply to sandwiches containing red meat. The steak sandwich scores red in all impact categories and is the least environmentally-friendly choice, followed by the filet american sandwich. The salmon sandwich can be considered the most environmentally friendly choice, as it scores green in almost all impact categories, except for freshwater eutrophication, where it scores yellow.

The interpretation of the findings clearly shows a trade-off between the completeness of the various environmental impacts and the consumer's ease of interpretation. An optimal solution would be to combine all six impact indicators into a single metric, allowing for easy environmental assessment and comparison between foods while providing a comprehensive picture of various environmental concerns. There is currently no method for combining all important impact indicators into a single metric (van Dooren et al., 2018). As a result, the correlated MTL shown in figure 18 is considered the best possible option for informing consumers about the environmental impact of their food choices in this study because it provides the best balance of completeness and simplicity of the three proposed traffic-light labels.

4 Sensitivity Analyses

In this chapter, two separate sensitivity analyses are performed. The first aimed at assessing the influence of the choice of system scope on the results. The second aimed at assessing the influence of the choice of the functional unit on the results. In both cases, we examine the impact of methodological choices on traffic light labels associated with environmental impact values, i.e., whether there are any changes from a red to, for example, a green label. As mentioned in the previous chapter, the label is green when a sandwich belongs to the lowest impact one-third of all sandwiches in the particular impact category. When the sandwich belongs to the middle third, the label is yellow, and when it belongs to the highest impact one-third, the label is red.

4.1 Sensitivity Analysis: System Scope

The dataset of the RIVM contained two different LCA datasets, one dataset with a 'cradle-to-gate' scope and one dataset with a 'cradle-to-consumption' scope. The FEI Model uses the 'cradle-to-consumption' dataset, as explained in section 2.2. A sensitivity analysis is performed to test the impact of this methodological choice on the color labels associated with the different environmental impacts of the sandwiches. The impact results of the nine sandwiches obtained using the dataset with a cradle-to-consumption scope (see Figure 21) were compared to the impact results when a 'cradle-to-gate' scope was used for the sensitivity analysis (see Figure 22).

Sandwich	GWP [kg CO2 eq]	TA [kg SO2 eq]	FE [kg P eq]	ME [kg N eq]	LU [m2*year]	WU [m3]
1 (Filet American)	🔴 0,855	🔴 0,0123	🟡 4,30E-05	🔴 2,23E-03	🔴 0,537	🔴 0,0110
2 (Ham)	🟡 0,581	🟡 0,0050	🔴 5,20E-05	🟡 8,05E-04	🟡 0,437	🟢 0,0081
3 (Cheese)	🔴 0,670	🔴 0,0081	🟢 3,00E-05	🔴 1,30E-03	🟢 0,317	🟡 0,0083
4 (Humus)	🟢 0,403	🟢 0,0011	🟢 2,80E-05	🟢 4,74E-04	🔴 0,517	🟡 0,0090
5 (Salmon)	🟢 0,413	🟢 0,0013	🟡 3,30E-05	🟢 4,20E-04	🟢 0,189	🟢 0,0060
6 (beef)	🔴 1,369	🔴 0,0221	🔴 6,00E-05	🔴 3,82E-03	🔴 0,721	🔴 0,0140
7 (mozzarella)	🟢 0,485	🟡 0,0055	🟢 2,40E-05	🟡 9,31E-04	🟢 0,241	🟢 0,0070
8 (Chicken)	🟡 0,583	🟢 0,0044	🔴 5,10E-05	🟢 5,94E-04	🟡 0,401	🔴 0,0100
9 (Goat Cheese)	🟡 0,488	🟡 0,0050	🟡 4,00E-05	🟡 9,41E-04	🟡 0,350	🟡 0,0090

Figure 21: Results obtained using a cradle-to-consumption scope

Sandwich	GWP [kg CO2 eq]	TA [kg SO2 eq]	FE [kg P eq]	ME [kg N eq]	LU [m2*year]	WU [m3]
1 (Filet American)	0,744	0,0111	3,82E-05	1,87E-03	0,482	0,0093
2 (Ham)	0,495	0,0045	4,68E-05	5,75E-04	0,392	0,0069
3 (cheese)	0,616	0,0078	2,72E-05	1,09E-03	0,297	0,0073
4 (humus)	0,339	0,0009	2,55E-05	2,82E-04	0,477	0,0074
5 (salmon)	0,354	0,0012	3,02E-05	2,33E-04	0,171	0,0046
6 (beef)	1,202	0,0200	5,34E-05	3,30E-03	0,646	0,0118
7 (mozzarella)	0,437	0,0052	2,19E-05	7,31E-04	0,223	0,0059
8 (chicken)	0,454	0,0035	4,04E-05	3,40E-04	0,318	0,0078
9 (goat cheese)	0,440	0,0047	3,71E-05	7,41E-04	0,329	0,0079

Figure 22: Results obtained using a cradle-to-gate scope

When comparing the results, there are only two differences in labels: when the scope is from cradle to consumption, the chicken sandwich has a red label, and the goat cheese sandwich has a yellow label, and vice versa when the scope is from cradle to gate. When comparing the quantitative values of these two sandwiches, it is clear that the difference that caused the label switch is minor. As a result, we can conclude that the system scope selection has no significant impact on the results.

4.2 Sensitivity Analysis: Functional Unit

The FEI Model uses a recipe-based functional unit, in this case, a 'sandwich-based' functional unit. However, this implies that recipes with different nutritional properties are directly compared, potentially resulting in biased results. In order to study how this methodological choice affects the results, a sensitivity analysis was performed comparing the results obtained using a sandwich-based unit with two alternative sets of results, calculated using different functional units. These were respectively 100 kcal and 1 g of protein. Each sandwich's energy and protein content were calculated based on the recipe and the energy/protein content of the ingredients, as provided in the NEVO database.

Sandwich	Quantity [gram]	Energy [kcal]	Protein [g]
1 (Filet American)	155	349	14,9
2 (Ham)	155	306	16,4
3 (Cheese)	155	402	18,4
4 (Humus)	155	383	12,3
5 (Salmon)	155	328	17,9
6 (beef)	155	315	20,1
7 (mozzarella)	155	356	16,7
8 (Chicken)	155	296	18,5
9 (Goat cheese)	155	335	14,6

Figure 23: Energy and protein content for each sandwich

The nutritional values in terms of energy and protein content can be observed in Figure 23. The global warming indicator values for the nine types of sandwiches calculated for the three functional units are shown in Figure 24. The results show that the functional unit chosen has a significant impact on the results, which is supported by literature (McLaren et al., 2021) (De Laurentiis et al., 2019) (Kendall, Brodt, et al., 2014). For example, the humus sandwich scored green with a recipe-based functional unit but red with a protein-based functional unit, while the chicken sandwich scored red with an energy-based functional unit but green with a protein-based functional unit.

When comparing the results, a negative relative can be observed between the energy content of the sandwiches and the global warming impact of the sandwiches when an energy-based functional unit is used. For example, a greater amount of chicken (low energy content ingredient) is required to obtain the same amount of energy as cheese (high energy content ingredient), resulting in chicken having a greater impact than cheese. The sandwiches with chicken, beef, and ham are relatively low in energy content and therefore present higher impacts than the other sandwiches when an energy-based functional unit is used. Vice versa, the sandwiches with mozzarella, cheese, and hummus have relatively high energy contents and therefore present lower impacts than the other sandwiches with an energy-based FU.

The same correlation can be observed in the results generated with a protein-based FU. Sandwiches low in protein are disadvantaged when a comparison is made based on 1 g of protein. For example, the sandwich with hummus which contains the fewest proteins of the nine sandwiches scored green with a sandwich-based functional unit but red with a protein-based functional unit. This can be explained by the fact that a greater amount of humus is required to obtain the same amount of protein like chicken, resulting in humus having a higher impact than chicken. Furthermore, it can also be observed that the choice of FU does not influence the sandwich with beef. Even though this sandwich has the highest protein content, it still has the most significant impact.

Sandwich	[kg CO2/sandwich]	[kg CO2/100 kcal]	kg CO2/g protein]
1 (Filet American)	0,855	0,416	0,075
2 (Ham)	0,581	0,434	0,059
3 (Cheese)	0,670	0,232	0,056
4 (Humus)	0,403	0,192	0,063
5 (Salmon)	0,413	0,317	0,051
6 (beef)	1,369	0,731	0,072
7 (mozzarella)	0,485	0,226	0,053
8 (Chicken)	0,583	0,484	0,055
9 (Goat cheese)	0,488	0,332	0,059

Figure 24: Results for the impact category 'Global Warming' for three different functional units

Appendix A.2 explains the results of the sensitivity analysis for the remaining five impact indicators. To conclude our findings, it can be stated that the choice of the functional unit significantly affects the results. When an energy-based functional unit was used instead of a sandwich-based functional unit, sandwiches with a low energy content were often disadvantaged. The same applies to using a protein-based functional unit for comparing environmental impact: sandwiches with a relatively low protein content will often be at a disadvantage compared to environmental impact results generated with a sandwich-based functional unit. However, this finding does not always hold. For example, the sandwich containing beef was infrequently affected by choice of functional unit (De Laurentiis et al., 2019).

It is critical to emphasize that a meal's energy and protein content do not provide a complete picture of its nutritional value. As a result, more complex functional units have been defined in a report of the FAO to capture the nutritional properties of various foods better when comparing their environmental impact (McLaren et al., 2021). Nonetheless, since the goal of the tool was to provide results that the consumer could easily interpret, a recipe-based functional unit was considered the most suitable option.

Discussion

This section discusses aspects of the study that could have influenced the outcome or could have been elaborated on.

The 'Selection of dataset' chapter revealed that the impact values of different datasets differed significantly. If a different dataset was used for this study, the model's output would be significantly different. Despite the significant differences in quantitative impact data, the qualitative interpretations that could be drawn from the data were the same for all three datasets.

The choice of the functional unit significantly impacts the results, as shown in the previous section. A mass-based/recipe-based functional unit was chosen for this research because this functional unit was used in the RIVM database. Even though this functional unit is considered appropriate for this research because it is simple for the consumer to understand, it does not represent the actual function of food to provide nutrition (Notarnicola et al., 2017). As a result, one of the study's limitations is that it compares the environmental impact of foods based on mass rather than product performance. The results would have been different if the comparison was based on nutritional performance.

This study was limited to secondary LCA data that was publicly available due to a lack of time and data from suppliers. The RIVM dataset used in this study included impact data from 238 products. The dataset makes no distinction between product brands. However, some brands may be more environmentally friendly than others; for example, an organic cheese brand may have a lower impact than a regular cheese brand in some impact categories. The more product differentiation there is, the more representative the results will be.

Furthermore, the RIVM dataset's cradle-to-plate scope applies only to home preparations where the consumer purchases the products in a supermarket. Catering-related products may have a different life cycle than those intended for home cooking. The results would be more representative if a dataset specific to the catering industry were used. However, RIVM is currently working on extending the RIVM dataset and making it more applicable to the catering industry. One of the options being considered is including additional data on (brand-) specific products in the dataset (Vlek et al., 2022).

Further Research

The FEI Model is capable of quantifying the environmental impacts of food only. However, food items sold at the university canteen are frequently packed in a material at the point of sale. The sandwiches, for example, are packed in a material consisting of paper and plastic. This material also has an environmental impact, but this was not taken into account in this study. Packaging material varies by product type and is an essential factor to consider when comparing the environmental impact of various products. Further research may include the addition of packaging materials to the FEI model, so that food packaging can also be included in quantifying and comparing the environmental impact of food products.

The FAO has identified standardization and harmonization of metrics for assessing food chain environmental impacts as an important research topic (van Dooren et al., 2018). The proposed environmental food label includes impact information on climate change, terrestrial acidification, and marine eutrophication; however, it does not capture the environmental concerns regarding freshwater eutrophication, land use, and water use. Future initiatives and research should consider the feasibility of developing a more multifaceted measurement that can incorporate these important factors affecting food production and consumption's environmental impact. The development of such a standardized measure would require a great deal of research and partnerships between industry, government, and consumer groups. Although this is a challenging task, creating a multifaceted label that consumers can easily understand and use to compare the sustainability aspects of products within and across product categories could significantly impact the market for sustainable food products. It could increase food producers' and consumers' awareness of product environmental impact and incentivize the food industry to improve product sustainability (Asioli, Aschemann-Witzel, & Nayga Jr, 2020).

Conclusion

The report's research goal was divided into two sections: a knowledge goal to improve The Green Office's understanding of the quantified environmental impact of food items served at the canteen and a design goal to create a communication tool to inform consumers about the environmental impact of their food choices.

In order to increase insight into the quantified environmental impact of food items offered at the canteen, the FEI Model was developed. The FEI Model enables The Green Office to quantify and compare the environmental impact of food items offered at the university canteen. The model generates six impact indicators: global warming potential, terrestrial acidification, freshwater eutrophication, marine eutrophication, land use, and water use. These six environmental impact indicators capture a substantial part of the food system's environmental impact. The results of the FEI Model can be used to identify 'hotspot' ingredients and recipes and to develop a communication tool to inform the consumer about the environmental impact of their food choices.

The FEI Model was used to quantify the environmental impact of nine different sandwiches. Of these sandwiches, the beef sandwich has the highest impact in all six categories, followed by the sandwich containing filet American. Within the meat options, the chicken sandwich had the lowest overall environmental impact, and within the cheese options, the mozzarella sandwich had the lowest impact. The sandwich with the lowest environmental impact was the sandwich containing salmon.

The report's second main section involved creating a design for a communication tool that would inform consumers about the environmental impact of their food choices. The proposed design of a communication tool is an evaluative traffic-light food label, where red indicates a high environmental impact, yellow a medium environmental impact, and green a low environmental impact. This evaluative type of food label format is considered more effective than an informative food label as it is easier to interpret by the consumer. The traffic light food label immediately provides the consumer an indication of the relative environmental impact of the food item compared to other products. Within this traffic-light label, three different types were evaluated: A single traffic light label presenting only one impact indicator, a multi-traffic light label presenting three correlated impact indicators, namely, global warming potential, terrestrial acidification, and marine eutrophication, and a traffic light label presenting all six impact indicators.

From these three formats, the multi-traffic light food label presenting three correlated impact indicators was considered to be the best possible option, as it offers the best balance between ease of interpretation and completeness in providing information on different environmental concerns.

Reflection

In this section, I explain how the course of the process evolved as I gained more insight into the subject. Research questions 1, 2, and 3 have been modified or not reflected in the report, and the reasoning for this is described below.

Research Question 1: *What is the nutritional content of consumption options supplied in the UoG canteen in terms of protein to normalize the environmental impact indicators?*

Initially, I selected a protein-based functional unit as the reference unit. Due to a lack of time and data from Beijk, I asserted that I could not conduct a primary LCA of food products. As a result, the functional unit I used for this study was determined by the functional unit used in the secondary LCA dataset. The RIVM dataset used a mass-based functional unit; therefore, this functional unit was used in this study and not a protein-based functional unit.

Research question 2: *What is the current quantified environmental impact of the consumption supplied in the UoG canteen in terms of greenhouse gas emissions?*

When I drafted this research question, I had little knowledge about the complexity of the environmental impact of food. After reading numerous scientific articles and conversing with an Environmental Sciences professor, I became aware that greenhouse gas emission is only a part of the various environmental impacts of the food system. After finding the environmental impact dataset of the RIVM, I was also able to express the environmental impact of food items in terms of water consumption, land consumption, freshwater eutrophication, marine eutrophication, and terrestrial acidification. All six impact indicators are essential for assessing food's environmental impact.

Research question 3: *What changes can be made to the canteen menu to reduce the environmental impact?*

In my search for an appropriate food LCA dataset, I found two articles from which the final FEI Model was inspired (Vlek et al., 2022)(De Laurentiis et al., 2019). Both studies present a model that can quantify the environmental impact of different recipes using secondary data. The focus of my report has shifted from providing advice on reducing the environmental impact of the menu to the development of the FEI model. Therefore, the report does not reflect the answer to research question three. However, the model does give the green office the information it needs to reduce the environmental impact of the canteen. Since the model provides insights into which food items have a high environmental impact and which food items have a low environmental impact. By changing the high-impact food items with low-impact items, the green office could reduce the impact of the canteen menu.

Initially, the plan was to calculate the environmental impact of a specific menu without using a model. The model offers more flexibility in assessing the environmental impact of different canteen menus. This is useful since the canteen menu can differ significantly from one canteen to another within the university. When the environmental impact was calculated for a specific canteen, it would not have said much about the environmental impact of the other canteens.

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A Appendices

A.1 Example FEI Model

This section provides an example of the calculation of the nutritional and environmental impact of an avocado for a given quantity, to demonstrate how the FEI model generates its values. The “” sign indicates the actions of the user, and the succeeding steps that the model performs are described.

Ingredient is filled in by user, in this case, ‘Avocado’.

Step 1: Model looks up for the NEVO-code in the “ingredient” sheet (list with ingredients and corresponding NEVO-codes) of the FEI Model. For avocado, the specific NEVO-code is 689.

Quantity is filled in by user, for example, ‘200 gram’

Step 2a: Model looks up corresponding nutritional data of NEVO-code 689 in the “nutritional value” sheet of the FEI Model. The functional unit used in the nutritional value dataset is ‘per 100 g of ingredient’. For avocado, the kilocalories content is thus 186 kcal per 100 g avocado, and the protein content is 2 g protein per 100 g of avocado. Consequently, the FEI Model calculates the protein and kilocalories content for filled in quantity in the following manner:

$$\text{kilocalories} = \frac{186[\text{kcal}]}{100[\text{g}]} \times 200[\text{g}] = 372 \text{ kcal}$$

$$\text{protein content} = \frac{2[\text{g}]}{100[\text{g}]} \times 200[\text{g}] = 4 \text{ g}$$

The values of the nutritional values must be divided by 100 g to obtain the nutritional value per gram. The corresponding user interface can be observed in Figure 25.

Recipe 1				
Ingredient	NEVO code	Quantity [g]	Energy [kcal]	Protein [g]
Avocado	689	200	372	4,0
Total		200	372	4,0

Figure 25: Corresponding user interface, presenting nutritional values of 200 g of avocado

Step 2b: Model looks up corresponding environmental impact data of NEVO-code 689 in the "Environmental Impact" sheet of the FEI Model. The functional unit used in this sheet is the environmental impact of indicator per 1 kg of ingredient. Consequently, the FEI model calculates the values of the impact indicators for the filled-in quantity for avocado in the following manner:

$$\text{Global Warming} = \frac{1,315[\text{kg CO}^2\text{ eq}]}{1000[\text{g}]} \times 200[\text{g}] = 0,263\text{ kg CO}^2\text{ eq}$$

$$\text{Terrestrial Acidification} = \frac{0,009[\text{kg SO}^2\text{ eq}]}{1000[\text{g}]} \times 200[\text{g}] = 0,00173\text{ kg SO}^2\text{ eq}$$

$$\text{Freshwater Eutrophication} = \frac{0,00015[\text{kg P eq}]}{1000[\text{g}]} \times 200[\text{g}] = 0,00003\text{ g}$$

$$\text{Marine Eutrophication} = \frac{0,001475[\text{kg N eq}]}{1000[\text{g}]} \times 200[\text{g}] = 0,000295\text{ g}$$

$$\text{Land Use} = \frac{2,168[\text{m}^2\times\text{ year crop eq}]}{1000[\text{g}]} \times 200[\text{g}] = 0,434\ [\text{m}^2\times\text{ year crop eq}]$$

$$\text{Water Use} = \frac{1,286[\text{m}^3]}{1000[\text{g}]} \times 200[\text{g}] = 0,257\ [\text{m}^2\times\text{ year crop eq}]$$

The values of the impact indicator must be divided by 1000 g to obtain the impact per gram. The corresponding user interface can be observed in Figure 26.

Global Warming [kg CO_2 eq]	Terrestrial Acidification [kg SO_2 eq]	Freshwater Eutrophication [kg P eq]	Marine Eutrophication [kg N eq]	Land Use [m2 *year crop eq]	Water Use [m3]
0,263	0,0017	0,000030	0,000295	0,434	0,2573
0,263	0,0017	0,000030	0,000295	0,434	0,2573

Figure 26: Corresponding user interface, presenting impact values of 200 g of avocado

Step 3: The FEI Model sums up the nutritional and environmental impact values in the ‘total’ row.

Step 4: The FEI Model creates pie diagrams for each impact indicator in the ‘Output’ sheet, using the values calculated in step 2a/2b.

A.2 Sensitivity Analysis: Functional Unit

The results of the terrestrial acidification impact calculations for the three different FUs are shown in Figure 27. From the results can be observed that the choice of FU has no effect on the impact values of sandwiches containing red meat. Furthermore, for the chicken sandwich, there is a significant difference in impact. The sandwich scores green with a protein-based FU, but it scores red with an energy-based FU, which can be explained in part by the relatively low energy content of chicken.

Sandwich	[kg SO2/sandwich]	[kg SO2/100 kcal]	[kg SO2/g protein]
1 (Filet American)	0,0123	0,0036	0,0006
2 (Ham)	0,0050	0,0025	0,0002
3 (Cheese)	0,0081	0,0016	0,0003
4 (Humus)	0,0011	0,0004	0,0001
5 (Salmon)	0,0013	0,0006	0,0001
6 (beef)	0,0221	0,0093	0,0006
7 (mozzarella)	0,0055	0,0015	0,0002
8 (Chicken)	0,0044	0,0026	0,0002
9 (Goat cheese)	0,0050	0,0018	0,0003

Figure 27: Results for the impact category 'Terrestrial Acidification' for three different functional units

Figure 28 shows the values of the freshwater eutrophication impact of the 9 types of sandwiches, calculated for the three chosen functional units. It can be observed that there are no differences in color labels between the sandwich-based and energy-based results. When comparing the results to the protein-based functional unit, some differences can be seen, for example, the sandwich with Filet American scores red instead of yellow, which can be explained by the sandwich's low protein content, which disadvantages it when a protein-based functional unit is used.

Sandwich	[kg P/sandwich]	[kg P/100 kcal]	[kg P/g protein]
1 (Filet American)	4,3E-05	1,81E-05	3,3E-06
2 (Ham)	5,2E-05	2,87E-05	3,4E-06
3 (Cheese)	3,0E-05	1,05E-05	2,3E-06
4 (Humus)	2,8E-05	1,06E-05	3,0E-06
5 (Salmon)	3,3E-05	1,69E-05	2,6E-06
6 (beef)	6,0E-05	2,92E-05	3,1E-06
7 (mozzarella)	2,4E-05	1,03E-05	2,2E-06
8 (Chicken)	5,1E-05	3,19E-05	3,0E-06
9 (Goat cheese)	4,0E-05	1,84E-05	3,2E-06

Figure 28: Results for the impact category 'Freshwater Eutrophication' for three different functional units

Figure 29 shows the values of the effect of the 9 types of sandwiches on marine eutrophication, calculated for the three chosen functional units. The graph shows that the choice of functional unit has an influence on the results, however, this influence is smaller than that observed for the global warming indicator. Some shifts can be observed between the successive color groups, but no major shifts such as from red to green or vice versa. As the graph shows, red meat and dairy products particular have a high impact on marine eutrophication (Xue & Landis, 2010).

Sandwich	[kg N/sandwich]	[kg N/100 kcal]	[kg N/g protein]
1 (Filet American)	2,2E-03	6,26E-04	1,1E-04
2 (Ham)	8,1E-04	3,59E-04	4,1E-05
3 (Cheese)	1,3E-03	2,75E-04	5,0E-05
4 (Humus)	4,7E-04	1,35E-04	3,9E-05
5 (Salmon)	4,2E-04	1,51E-04	2,6E-05
6 (beef)	3,8E-03	1,57E-03	1,1E-04
7 (mozzarella)	9,3E-04	2,63E-04	4,4E-05
8 (Chicken)	5,9E-04	2,94E-04	3,0E-05
9 (Goat cheese)	9,4E-04	3,09E-04	5,4E-05

Figure 29: Results for the impact category 'Marine Eutrophication' for three different functional units

Figure 30 depicts the land use of the nine types of sandwiches, calculated for the three functional units. The results show that there are no differences in color labels when comparing the sandwich-based results with the protein-based results. Furthermore, it can be concluded that the values of dairy products for land use are also not influenced when a protein-based functional unit is used. Moreover, when an energy-based functional unit is used, the sandwich with chicken scores red, which can be explained by the fact that chicken has a low energy content and therefore will be disadvantaged when a comparison is made based on energy content. The sandwich containing beef is not affected by the choice of functional unit, even despite its high protein content, the sandwich still scores red on land use when a protein-based functional unit is used.

Sandwich	[m2*year/sandwich]	[m2*year/100 kcal]	[m2*year/g protein]
1 (Filet American)	0,537	0,155	0,028
2 (Ham)	0,437	0,199	0,020
3 (Cheese)	0,317	0,075	0,014
4 (Humus)	0,517	0,120	0,043
5 (Salmon)	0,189	0,068	0,011
6 (beef)	0,721	0,294	0,023
7 (mozzarella)	0,241	0,072	0,013
8 (Chicken)	0,401	0,215	0,017
9 (Goat cheese)	0,350	0,116	0,020

Figure 30: Results for the impact category 'Land Use' for three different functional units

The results of the water consumption of the sandwiches, calculated for the three different functional units, are shown in Figure 31. Based on the findings, it can be concluded that the functional unit selection has a significant impact on water consumption values. Chicken, for example, scores red when using a sandwich-based and energy-based functional unit, but green when using a protein-based functional unit, which can be explained by chicken's high protein content. Unlike the cheese sandwich, which scores red when a protein-based functional is used despite the high protein value of cheese.

Sandwich	[m3/sandwich]	[m3/100 kcal]	[m3/g protein]
1 (Filet American)	0,0110	0,0122	0,0022
2 (Ham)	0,0081	0,0123	0,0020
3 (Cheese)	0,0083	0,0078	0,0022
4 (Humus)	0,0090	0,0080	0,0025
5 (Salmon)	0,0060	0,0109	0,0019
6 (beef)	0,0140	0,0144	0,0021
7 (mozzarella)	0,0070	0,0078	0,0022
8 (Chicken)	0,0100	0,0138	0,0020
9 (Goat cheese)	0,0090	0,0119	0,0021

Figure 31: Results for the impact category 'Water Use' for three different functional units