FACULTY OF
BIOSCIENCE ENGINEERING

WHAT ARE THE ENVIRONMENTAL EFFECTS OF DIETS?

A CASE STUDY ON AN OMNIVOROUS AND A VEGETARIAN DIET AND THEIR ASSOCIATION WITH TYPE 2 DIABETES MELLITUS

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Preface

I am ecstatic and proud to present you this thesis, a work made possible through the support and guidance of numerous individuals, to whom I am deeply grateful.

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I can truly say that my growth throughout this year is thanks to all of you.

Sincerely,

Louise Van Stratum

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List of abbreviations

Abbreviation	***Definition***
AB	Attributable burden
BFCS	Belgian Food Consumption Survey
CVD	Cardiovascular disease
DALYs	Disability-adjusted life years
EoL	End-of-Life
FAO	Food and Agriculture Organization of the United Nations
FU	Functional unit
GHGEs	Greenhouse gas emissions
GHGs	Greenhouse gases
GP	General practitioner
HbA_{1c}	Glycated hemoglobin level
HRQoL	Health-related quality of life
HVAC	Heating, ventilation and air-conditioning
ISO	International Organization for Standardization
LCA	Life cycle assessment
LCI	Life cycle inventory
LCIA	Life cycle impact assessment
PAF	Population attributable fraction
ROS	Reactive oxygen species
RR(x)	Relative risk
SFAs	Saturated fatty acids
T1DM	Type 1 diabetes mellitus

T2DM	Type 2 diabetes mellitus
TZD	Thiazolidinediones
WHO	World Health Organization
WSI	Water scarcity intensity
YLD	Years lived with disability
YLL	Years of life lost

Abstract

This thesis compared the environmental and health impacts of Belgian vegetarian and omnivorous diets accounting for the risk of type 2 diabetes mellitus (T2DM) resulting from red meat intake. The direct environmental effects (e.g. dietary intake) and indirect effects related to the risk and treatment of T2DM in Belgium are included. A cradle-to-grave life cycle assessment methodology covered five impact categories: climate change, water use, land use, fossil resource use and freshwater ecotoxicity. The functional unit (FU) was defined as "the yearly dietary intake and treatment of T2DM linked to red meat consumption of 1000 Belgian adults". Disability-adjusted life years (DALYs) were calculated to assess the health impacts of climate change and T2DM itself. Three treatment scenarios were included: insulin use, metformin use or both combined. The omnivorous diet showed a greater overall environmental impact, scoring higher on all impact categories except water use. For example, it produced 1.7 times more kg CO_2 eq. per FU, primarily (42.7%) from agricultural practices for meat production, particularly red meat. When the direct environmental impacts were readjusted to reflect those suffering from T2DM, the indirect effects accounted for 9.8% of the climate change impact difference between both diets. At the individual patient level, the combination treatment scenario had the highest impact across all categories, with insulin supply, especially energy and tryptone use, being the predominant contributors, followed by the transportation and energy used for the visits to the caregivers. Lastly, the omnivorous diet resulted in 2.4 times more DALYs than the vegetarian diet, with 23.9% directly related to suffering from T2DM and 76.1% due to environmental effects.

Samenvatting

Deze thesis vergeleek de milieu- en gezondheidseffecten van Belgische vegetarische en omnivore diëten, rekening houdend met het risico op type 2 diabetes mellitus (T2DM) als gevolg van de inname van rood vlees. De directe milieueffecten (bv. voedingsconsumptie) en de indirecte effecten met betrekking tot het risico en de behandeling van T2DM in België zijn opgenomen. Een *cradle-to-grave* levenscyclusanalysemethodologie omvatte vijf impactcategoriën: klimaatverandering, watergebruik, landgebruik, gebruik van fossiele grondstoffen en zoetwaterecotoxiciteit. De functionele eenheid (FU) werd gedefinieerd als “de jaarlijkse voedingsinname en behandeling van T2DM gekoppeld aan de consumptie van rood vlees van 1000 Belgische volwassenen”. De *disability-adjusted life years* (DALYs) werden berekend om de gezondheidseffecten van klimaatverandering en T2DM zelf te beoordelen. Drie behandelingsscenario's werden opgenomen: insulinegebruik, metforminegebruik of beide gecombineerd. Het omnivore dieet had een grotere algemene impact op het milieu en scoorde hoger op alle impactcategorieën behalve watergebruik. Het produceerde bijvoorbeeld 1,7 keer meer kg CO_2 eq. per FU, voornamelijk (42,7%) door landbouwpraktijken voor de productie van vlees, met name rood vlees. Wanneer de directe milieueffecten aangepast werden aan de mensen die T2DM hebben, waren de indirecte effecten goed voor 9,8% van het verschil in klimaatverandering tussen beide diëten. Op het niveau van de individuele patiënt had het scenario van de combinatiebehandeling de grootste impact in alle categorieën, met de insulinetoevoer en meer specifiek het energie- en tryptoongebruik, de grootste bijdrage, gevolgd door het transport en energiegebruik voor de bezoeken aan de zorgverleners. Tot slot resulteerde het omnivore dieet in 2,4 keer meer DALYs dan het vegetarische dieet, waarbij 23,9% direct gerelateerd was aan het lijden aan T2DM en 76,1% aan milieueffecten.

1. Introduction

In recent years, the environmental impact of different diets - more specifically the impact of the food items within a diet - has gained significant attention due to growing concerns about sustainability. For example, the production and consumption of red meat exert great pressure on the environment, by emitting substantial amounts of greenhouse gases (GHGs) (e.g. methane) and requiring extensive land use, which contributes to deforestation and habitat loss (Chai et al., 2019; Gerber et al., 2015). However, people tend to overlook the more indirect environmental impacts associated with health problems linked to these dietary choices. For instance, many common diets contain high amounts of saturated fats, sugars, red meat, etc., which are considered unhealthy and might lead to several non-communicable diseases, such as cardiovascular disease (CVD), cancers and type 2 diabetes mellitus (T2DM), strongly affecting human health. (Khazrai et al., 2014; Rosi et al., 2017). Accordingly, the treatments (e.g. medication, hospitalization, etc.) required to manage these diseases, further aggravate environmental impacts.

Furthermore, T2DM, in particular, is a disease that has emerged as an escalating global health problem since its prevalence keeps increasing. This is mainly due to an unhealthy diet and other risk factors such as a sedentary lifestyle (WHO, 2023; Zheng et al., 2018). Moreover, recent research has suggested a certain association between high red meat intake and the increased risk of T2DM, highlighting the crucial role of diet in the risk and management of T2DM (Aune et al., 2009).

This thesis will specifically evaluate and compare the environmental and health effects of omnivorous and vegetarian diets within the Belgian context by conducting a life cycle assessment (LCA). LCA is a method to investigate the environmental impacts of a product throughout its entire life cycle, from the extraction of raw materials to disposal. The study will assess both the direct environmental impacts, due to dietary intake, and the indirect effects associated with the treatment of T2DM resulting from red meat consumption.

2. Literature review

2.1. What is diabetes?

Diabetes remains a major global health concern to this day, affecting 1 out of 10 adults worldwide (International Diabetes Federation (IDF), 2021; Wu et al., 2014). Diabetes, which is characterized by high blood glucose levels increasing the risk for life-threatening complications, is in ninth place considering mortality (WHO, 2023; Zheng et al., 2018). While these numbers are reported for diabetes in general, it is crucial to differentiate between the two dominant types of diabetes, namely type 1 diabetes mellitus (T1DM) also known as insulin-dependent diabetes and type 2 diabetes mellitus (T2DM) or non-insulin-dependent diabetes (Wu et al., 2014). Around 90 to 95% of diabetes patients suffer from the latter and the prevalence will only continue to increase worldwide (Aune et al., 2009; Saini, 2010). According to Mathieu et al. (2019), 5% of the Belgian population suffered from T2DM in 2019, which has increased since then (IMA, 2021; Mathieu et al., 2019). In addition, one-third of the T2DM patients in Belgium are unaware of the fact that they suffer from this disease, which consequently leads to an even higher estimated prevalence of 10% (Sciensano, 2023). There are several reasons for this increase such as global aging, sedentary lifestyles and unhealthy diets such as diets high in red meat (Zheng et al., 2018). These factors are thus often preventable, unlike T1DM, which is an autoimmune disease (Popoviciu et al., 2023). However, it is important to note that besides health-related consequences such as a risk of T2DM, these unhealthy diets also carry high direct and indirect environmental impacts, with the latter due to for example T2DM treatment. Because of this global threat, both to health and the environment, it is crucial to understand the impact of diets on this disease and to enhance communication around the different prevention methods, available treatments, and their associated environmental impacts.

2.1.1. Type 2 diabetes mellitus

T2DM is a highly complex metabolic disorder, which potentially results from a combination of genetic, environmental, and lifestyle factors (Wu et al., 2014). As every country has different habits and climates, the prevalence of T2DM varies a lot geographically (Olokoba et al., 2012). Some countries for example have colder climates, leading to people staying inside more frequently and exercising less, which is a risk factor for T2DM (elaborated in section 2.1.2.). In addition, according to a review by Kolb *et al.* (2017), T2DM has also shown a higher prevalence among men compared to women and there is a higher occurrence in low to middle-income countries (Kolb & Martin, 2017). Yet, another lifestyle factor positively associated with the prevalence of T2DM is the human diet, more specifically unhealthy diets such as high red meat intake (Aune et al., 2009). To understand how these different factors potentially contribute to T2DM, it is crucial to comprehend the working mechanisms of T2DM, as will be explained below.

In general, diabetes (both T1DM as well as T2DM) is linked to blood sugar or glucose levels (glycemia), which are regulated by insulin and glucagon (Caruso et al., 2023). Insulin is a hormone produced in the beta-cells of the pancreas and is used to activate glucose transport and its uptake into bodily tissues (Choi & Kim, 2010). On the other hand, the alpha cells of the pancreas produce the hormone glucagon, which is used to activate glucose transport from the liver back to our blood. In other words, insulin and glucagon are antagonists, as the former will lower the blood sugar level and the latter will increase the blood sugar level (Hædersdal et al., 2023). Individuals with T2DM struggle to utilize insulin efficiently in their bodies (Khazrai et al., 2014). This is because (a combination of) several environmental, lifestyle, and genetic factors can potentially lead to insulin resistance, as depicted in ***Figure 1*** (Mahler & Adler, 1999).

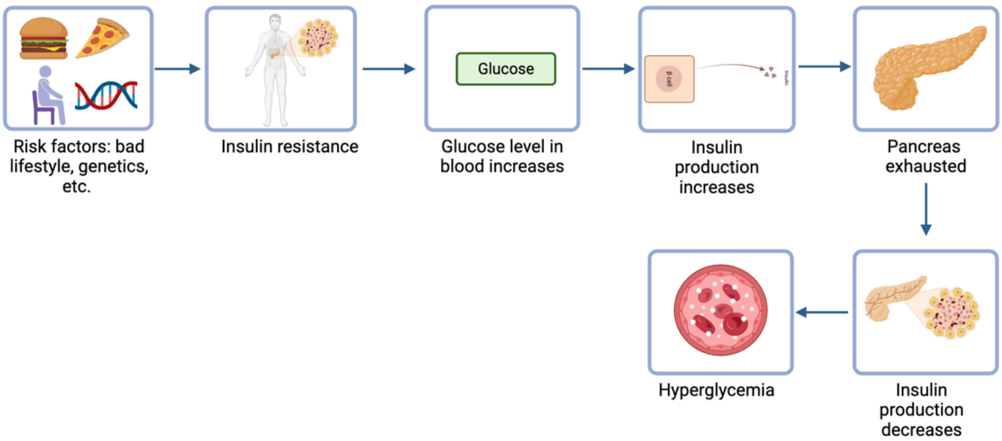

Figure 1: Working mechanism of type 2 diabetes mellitus*. Insulin resistance is when the cells become less responsive to insulin* (Mahler and Adler, 1999). *Hyperglycemia, also known as high blood sugar level* (Zheng et al., 2018) *(Figure created in Biorender.com based on the content of Mahler & Adler (1999), Olokoba et al. (2012) and Zheng et al. (2018)).*

The glucose transport and uptake into the liver, muscle, and fat cells will decline, as the cells become less responsive to insulin, referred to as insulin resistance. Consequently, the beta-cells will first produce more insulin to compensate for the rise in blood glucose, but after a while, the pancreas will become exhausted and the beta-cell function will decline (Olokoba et al., 2012; Saini, 2010). Conversely, the alpha-cells will still produce glucagon, which also results in the release of glucose into the bloodstream (Olokoba et al., 2012). The combination of the latter with insulin resistance and beta-cell dysfunction leads to high blood sugar levels, also known as hyperglycemia (Mahler & Adler, 1999; Olokoba et al., 2012; Zheng et al., 2018). As a result, several complications may arise, which will be discussed further in section 2.1.3.

There are different methods available for diagnosing T2DM. The World Health Organization (WHO) has advised using the glycated hemoglobin (HbA_{1c}) level, which is the average glycemia of the past 2 to 3 months. An HbA_{1c} level of 6.5% or more is considered the threshold for diagnosing T2DM (Koeck et al., 2015; WHO, 2011). Another option is to measure the fasting glycemia level. For the latter T2DM is diagnosed when two blood samples show a glycemia of $\geq$126 mg/dl (Koeck et al., 2015).

2.1.2. Risk factors of T2DM

As discussed above (section 2.1.1.), there are different lifestyle, genetic and environmental factors contributing to the risk of T2DM (Zheng et al., 2018). A more detailed overview of the different risk factors is depicted in ***Figure 2***.

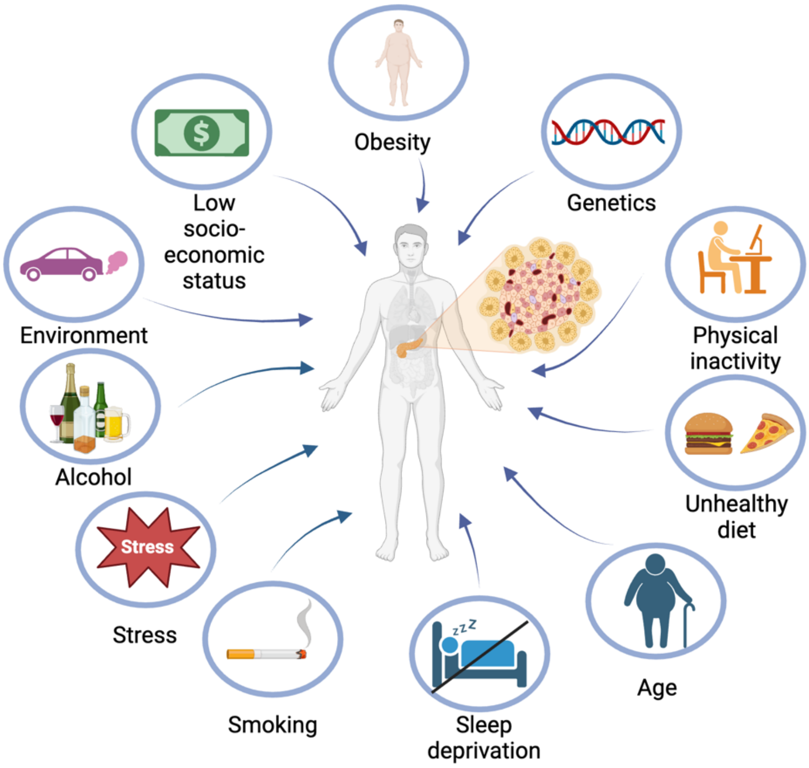

Figure 2: Different risk factors of type 2 diabetes mellitus. *These include lifestyle, genetic and environmental factors* (Zheng et al., 2018). *(Figure created in Biorender.com based on the content of Cannon et al. (2018), Olokaba at al. (2012) and Wu et al. (2014)).*

One of the most important drivers of T2DM is obesity, as it results in insulin resistance and visceral adiposity (Wu et al., 2014). Visceral adiposity refers to the accumulation of fat around internal organs and is considered more threatening than subcutaneous fat. This is because it releases proteins (adipocytokines) that can cause inflammation and hypertension, which contribute to insulin resistance as well (Jung et al., 2016; Olokoba et al., 2012; Wu et al., 2014). Since obesity results from an imbalance between energy uptake and consumption, besides the fact that it is often inherited, changing to a healthier diet and increasing physical activity may decrease the risk of T2DM directly and indirectly by preventing or treating obesity (Olokoba et al., 2012; Wu et al., 2014). Important to note is that by increasing daily movement, the cells become more sensitive to insulin, or in other words, insulin resistance decreases (Wu et al., 2014). Reducing the risk of T2DM by modifying the diet and physical activity is elaborated in section 2.1.4.

Furthermore, different studies showed that the risk of T2DM increases with age. The majority of patients are 45 and older. On the other hand, the number of younger patients is also increasing, as the abundance of child obesity is rising (Wu et al., 2014). These younger patients face a higher risk of chronic complications since they could be exposed longer to the illness, if not treated. In addition, sleep deprivation, smoking and stress may also increase the risk of T2DM among others (Chen et al., 2012). Note that it is often the combination of several factors that leads to T2DM (Kolb & Martin, 2017).

2.1.3. Complications of T2DM

Due to its hyperglycemic nature (section 2.1.1.), T2DM is often associated with several macro- and microvascular complications (***Figure 3***), affecting patient's mental and physical health. In other words, people suffering from this disease experience a decline in their life expectancy and general health-related quality of life (HRQoL), especially when untreated or undiagnosed (Cannon et al., 2018).

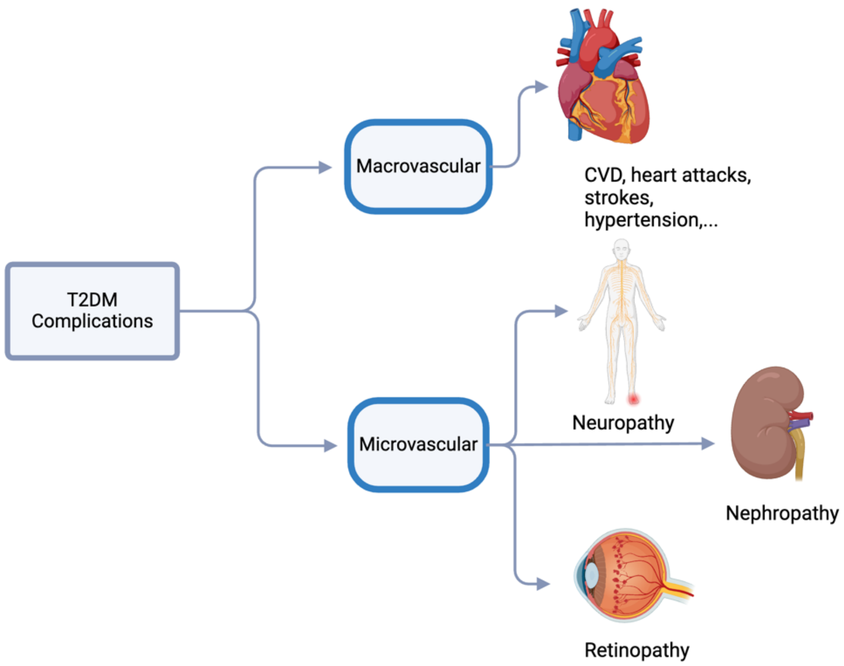

***Figure 3: Macrovascular and microvascular complications of type 2 diabetes mellitus**. Neuro-, nephro- and retinopathy refers to a disease related to the nerve system, kidneys and eyes, respectively* (Wu et al., 2014; Zheng et al., 2018). *Abbreviations: T2DM: type 2 diabetes mellitus; CVD, cardiovascular disease. (Figure created in BioRender.com based on the content of Wu et al. (2014) and Zheng et al. (2018)).*

First of all, cardiovascular disease (CVD), which is a macrovascular complication of diabetes, is considered the primary cause of death among T2DM patients. CVD includes coronary heart disease, cerebrovascular disease and others, which often result in heart attacks or strokes (Zheng et al., 2018).

Furthermore, neuro-, nephro- and retinopathy are the major microvascular complications of diabetes, increasing morbidity and mortality (Zheng et al., 2018). Out of all these, peripheral neuropathy is the most prevalent among T2DM patients and causes a lot of pain. It is a consequence of chronic hyperglycemia, where the nervous system is damaged and the sensory function declines. This consequence may eventually also lead to amputations, resulting in trauma and reduced HRQoL (Feldman et al., 2019). Nephropathy is yet another severe complication where the kidney is affected, resulting in renal (kidney-related) failure (Samsu, 2021). Consequently, this leads to around 10% of the total mortality among T2DM patients (Zheng et al., 2018). In addition to the affected nervous system and the kidney, the eyes, in particular the eye vessels, may also become damaged as a consequence of T2DM. This is because of the high blood glucose levels that T2DM patients endure (Wu et al., 2014). Retinopathy or eye damage leads to vision loss and affects people’s HRQoL as some might not be able to work or participate in different activities (Cannon et al., 2018).

Finally, T2DM may also result in other complications like higher infection risks, depression, anxiety and even several cancers such as colorectal, breast, and liver cancer (Wu et al., 2014). It is important to note that early diagnosis and treatment may be able to prevent these complications.

2.1.4. Prevention of T2DM

Due to many complications and the disease itself, T2DM patients suffer from a lot of health, social and economic burdens. Therefore, it is crucial to prevent the disease occurrence and/or progression and consequently stop its global spreading. Motivating patients to obtain a healthy diet and enough physical activity, are two crucial factors in the prevention of T2DM as they lead to a healthy body weight, which in turn might prevent or delay the progression of T2DM in many cases (Chen et al., 2012) (section 2.1.2). Moreover, an unhealthy diet including high consumption of red and/or processed meat, total and saturated fats, soft drinks, alcohol, and low dietary fiber increases insulin resistance and consequently the risk of T2DM (Zheng et al., 2018). For example, red meat, in particular, contains large amounts of total and saturated fat which may lead to obesity and thus also to T2DM. In general, meat also consists of heme-iron, which might increase oxidative stress and thus damage the beta-cells (Aune et al., 2009). Within this regard, it has been advised for people with a high risk of T2DM to change to a healthier diet, containing whole grains, vegetables, nuts, and legumes (Kolb & Martin, 2017). The Mediterranean diet is a typical example of such a healthy diet, which will also decrease the risk of CVD and retinopathy (Zheng et al., 2018). As mentioned above, a second crucial lifestyle modification to prevent T2DM is an increase in physical activity (walking, swimming, running, etc.). According to a review by Wu *et al*., this in combination with a healthier diet might decrease the risk by 30 to 50%, as it will result in weight loss: “Each kilogram of weight loss is correlated with a 16% reduction in the development of T2DM.” (Wu et al., 2014). The underlying reason for this is that a decrease in intra-abdominal fat and an increase in blood flow to insulin-sensitive tissues leads to the restoration of glucose tolerance and insulin sensitivity (Mahler & Adler, 1999).

Besides a healthy diet and physical activity, a high risk for T2DM might also be prevented in some cases by avoiding smoking and not drinking alcohol in excessive amounts. In particular, smokers have a higher incidence of central fat accumulation than non-smokers and thus a higher risk (45%) for insulin resistance (Zheng et al., 2018).

2.1.5. Treatments for T2DM

Lifestyle modifications such as a healthier diet, increasing physical activity and quitting smoking have shown promising results in reducing the risk and progression of T2DM (Wu et al., 2014). Several studies mentioned in the review by Zheng *et al.* (2018) indicated that these modifications are even more promising than some medications for T2DM (Zheng et al., 2018). Although in many cases, the disease is too evolved or some might be unwilling or unable to adjust their lifestyle, hence further treatment is necessary. About the latter, a division can be made between oral and injectable medications, but there are also alternative treatments for specific cases, as will be discussed below (Wu et al., 2014).

2.1.5.1. Oral medication

When lifestyle modifications are insufficient to treat T2DM, oral medication is suggested (Wu et al., 2014). Biguanides are the first important class of oral anti-diabetic medication, with metformin being the most used among diabetes patients (Rojas & Gomes, 2013). This drug lowers the blood glucose level and increases insulin sensitivity and is usually the first drug advised (Wu et al., 2014). Consequently, insulin resistance will decrease as well as the hepatic (liver) glucose output (Mahler & Adler, 1999). In addition, a review by Olokoba *et al.* (2012), referred to the fact that several studies also showed a lower risk for hypoglycemia compared to other drugs (Olokoba et al., 2012). Regarding the target group, metformin can be used for obese patients as it will not result in weight gain (Rojas & Gomes, 2013). Furthermore, although it will also reduce the risk of CVD, it should not be given to elderly people with kidney dysfunction as it may also lead to lactic acidosis (Olokoba et al., 2012). Finally, when metformin and lifestyle modifications are not sufficient, insulin injections are often added to the treatment, as elaborated in section 2.1.5.2. (Wu et al., 2014).

The second oral anti-diabetic class is the sulfonylureas, which will directly work on the beta-cells of the pancreas (Wu et al., 2014). In particular, these drugs are used to increase insulin secretion from the latter (Mahler & Adler, 1999). Because of this, they have a higher risk of hypoglycemia compared to metformin. However, unlike metformin, sulfonylureas are not suited for very obese patients as they will exacerbate weight gain (Wu et al., 2014).

Lastly, thiazolidinediones (TZD) are the third class of oral medications. They are used as insulin sensitizers as they decrease insulin resistance (Mahler & Adler, 1999) and are often used in combination with metformin or insulin injections. Although there is no increase in the risk of hypoglycemia, it does result in weight gain and the likelihood of bladder cancer rises when TZD are used (Wu et al., 2014). Besides these medications, there are also others available like alpha-glucosidase inhibitors, incretin-based therapies and GLP-1 receptor agonists (Olokoba et al., 2012).

2.1.5.2. Injectable medication

When oral medication is inadequate, patients are treated with insulin injections, often in combination with oral drugs. Insulin is considered the most efficient anti-hyperglycemic drug as it is used to increase insulin sensitivity, beta-cell function and improve metabolic abnormalities. Furthermore, this drug comes in different injectable forms: rapid-, short-, intermediate- and long-acting. The latter will have a lower risk for hypoglycemia compared to the other forms (Wu et al., 2014). However, insulin has a history of causing weight gain in obese patients and has a relatively high risk for hypoglycemia. For this reason, it is often used in combination with oral anti-diabetic drugs like metformin (Mahler & Adler, 1999).

2.1.5.3. Other treatments

Besides medication, other treatments are also available for T2DM. However, note that these are less researched and therefore less used. For example, according to a review by Wu *et al.* (2014) patients with T2DM show signs of a malfunctioning immune system, which could be controlled by the so-called stem cell educator therapy (Wu et al., 2014). Concerning this treatment, the patient's blood is first collected, and the lymphocytes (white blood cells) are purified. Then, they are cultured together with “adherent cord blood-derived multi-potent stem cells”, whereafter solely the now-educated lymphocytes are delivered into the patient’s blood system. After this treatment, several patients showed a rise in insulin sensitivities and enhancement of the metabolic system. Thus, although this therapy is not commonly utilized among T2DM patients, it shows promising results in improving the HRQoL of T2DM patients (Wu et al., 2014).

Another non-medicinal treatment is weight loss surgery or bariatric surgery. In particular, the performance of the latter can prevent T2DM by addressing obesity and overweight, which are two serious risk factors for T2DM. Nonetheless, these surgeries are costly and are insufficient to cure all patients. Because of this, it is crucial to prevent and treat obesity and consequently T2DM, especially through lifestyle modifications (Zheng et al., 2018).

2.1.5.4. Environmental impact of treatments

The management and treatment of T2DM involve a broad spectrum of factors that should be considered when assessing the impact on the environment. These healthcare aspects contribute to approximately 4 to 5% of global greenhouse gas emissions (Rodríguez-Jiménez et al., 2023). For example, as a first factor, the pharmaceutical industry exerts great pressure on the environment and the carbon footprint by producing all the necessary medicines for the healthcare sector (Benetto et al., 2018; Chai et al., 2019). This includes both the synthesis of the active pharmaceutical ingredient, as well as the production, packaging and distribution of the drug itself (Debaveye et al., 2019a). Secondly, as insulin must be injected into the patient, the environmental impact regarding needle waste management should be taken into consideration. Besides this, T2DM patients also require blood glucose testing devices (e.g. monitors), which need to be produced as well. All these processes exert different pressures on land use, water consumption, global warming, etc. (Eckelman & Sherman, 2016).

To ensure high quality of medication and testing devices (e.g. monitors, test strips, etc.) numerous clinical trials are performed yearly (Billiones, 2022). These trials, however, have a high carbon footprint, which may be addressed by simplifying the processes and therefore increasing the efficiency. In addition, reducing the weight of the used materials and packaging is especially crucial, as heavier materials result in higher emissions during shipment. Important to note, is that these packaging should still guarantee sterility (Subaiya et al., 2011). Finally, the transportation of staff members should also be minimized to obtain lower carbon emissions (Billiones, 2022).

Furthermore, since T2DM patients are being monitored closely, visits to the general practitioner (GP) and hospitals must also be taken into account. Moreover, some patients are admitted for several days at the hospital; as a consequence water, electricity and chemicals (for disinfection) are necessary (Debaveye et al., 2019a). According to Debaveye *et al.* (2019) car transport to the GP and/or hospital is a big environmental polluter (Debaveye et al., 2019a). Regarding this, the government has an essential role in educating the population about these impacts and encouraging them to use active modes of transportation such as walking and biking. This will not only mitigate climate change but also combat a sedentary lifestyle, thereby reducing the risk of developing T2DM. Thus, it is obvious that preventing this disease in the first place will exclude all these negative impacts on the environment. However, as prevention is not always possible, it is crucial to reduce the impacts by using renewable energy and obtain an overall low-impact production process (Wilkins, 2020). Generally, there is little to be found on the precise environmental impact of T2DM, which demonstrates the importance of this study and its relevance for the thesis.

2.2. Different diets and their environmental and health impacts

Different diets have a distinct impact on the environment as well as on human health, with the latter also affecting the environment indirectly, as discussed in section 2.1. For example, there are a lot of different steps to produce food including agricultural and feedstock activities, industrial processing, cooling and transportation among others, which all directly affect the environment in different ways (González-García et al., 2018). According to several studies mentioned by Rabès *et al.* (2020), the food industry is responsible for 20 to 30% of the total greenhouse gas emissions (GHGEs) (Rabès et al., 2020). Thus, it is common knowledge that the food industry forms a burden on land and water resources and plays a role in exacerbating climate change and related issues (Chai et al., 2019). Moreover, given the prominence of global warming over the last decade, it is crucial for consumers to not only comprehend the direct but also the indirect environmental impacts their dietary choices exert, with the former further elaborated in this section. Additionally, the health effects of different diets are explained.

2.2.1. The omnivorous diet

As discussed above, the choice of a diet has a diverse range of environmental and health consequences, with the latter impacting the environment indirectly as discussed in section 2.1 (Benetto et al., 2018). In most countries, the omnivorous diet, containing all the different animal- and plant-based food groups (meat, fish, vegetables, etc.), is the most prevailing choice (Wolk, 2017). For example, 54.8% of the Belgian population consider themselves as omnivores, consuming meat or fish every day. However, another 43.4% are flexitarians who also eat meat and fish but limit their intake to a few times a week (Rubens et al., 2023).

2.2.1.1. Health effects of the omnivorous diet

Since meat is a high source of proteins and micronutrients such as minerals and vitamins, the omnivorous diet (or any diet including meat) offers several health benefits (Clarys et al., 2014). An important example of this is for instance the mineral iron, which is necessary for several important processes in our body, like the transportation of oxygen. More specifically, iron extracted from animal-based foods, also called heme iron, is besides being highly abundant in red meat more bioavailable than plant-based non-heme iron (McAfee et al., 2010). Thus, by taking this into account, consuming meat can be considered beneficial (Wyness et al., 2011). However, the latter does not apply when ingesting it in larger quantities as a higher consumption of red meat is associated with several non-communicable diseases, such as T2DM (Khazrai et al., 2014). In particular, recommendations are to not eat more than 25 grams of red meat per day (Hoge gezondheidsraad, 2019).

There are several reasons for the association between high red meat consumption and T2DM. First of all, besides the important proteins and micronutrients, meat also contains a lot of saturated fatty acids (SFAs). However, the exact amount present depends on the type of meat and whether the animal is ruminant or not. For example, red meat (beef, pork, lamb and mutton) contains rather high amounts of SFAs (Wyness et al., 2011). An elevated intake of SFAs (due to high consumption of red meat) may lead to T2DM indirectly through an increased risk of insulin resistance, as explained in section 2.1. Secondly, excessive intake of heme iron from meat can be rather harmful, on the contrary with its beneficial effects when consumed in lower amounts (Aune et al., 2009). Moreover, it might increase oxidative stress by forming reactive oxygen species (ROS) which damages tissues like the beta-cells of the pancreas (Aune et al., 2009; Pan et al., 2011). Another reason for the increase in the risk of T2DM might be the high amounts of nitrites added to processed meat for its preservation (Aune et al., 2009). Namely, these are converted into nitrosamines in our bodies, which are toxic for the beta-cells. Finally, red meat consumption has also been associated with weight gain, which is yet another important risk factor for T2DM (Pan et al., 2011).

According to a review by González *et al.* (2020), one possibility to decrease the risk of T2DM could be to replace red meat with fish or poultry, though this seems difficult to apply globally (González et al., 2020a). A more appropriate solution could be to just consume not more than the recommendation for red meat. However, it should be kept in mind that there are different risk factors of T2DM and that high red meat consumption is just one of them (***Figure 2****)* (Zheng et al., 2018).

2.2.1.2. Direct environmental effects of the omnivorous diet

In addition to some (un)healthy aspects associated with an omnivorous diet, meat also carries a variety of negative environmental pressures, which contribute to global warming. In particular, several studies, mentioned in a review by González *et al.* (2020) confirm that an omnivorous diet exerts the highest environmental impacts concerning for example, GHGEs, land use, water use and acidification, compared to other diets such as a vegetarian diet (González et al., 2020b).

First of all, this is because the agricultural activities required to feed the livestock (e.g. cultivation of crops) should also be taken into consideration. Secondly, as the demand for meat has increased tremendously in the last decades, the consequential agricultural overexploitation has led to an overall high land use resulting into biodiversity and habitat losses. Moreover, the livestock industry is responsible for 12 to 18% of the global GHGEs (González et al., 2020b). The most important GHGs emitted by this industry are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) (Scarborough et al., 2014). Among these, CO_2 is mainly emitted through the transportation and processing of meat, as well as through deforestation for agricultural processes (such as feed production). On the other hand, CH_4 is primarily produced by livestock through fermentation processes during feed digestion, while N_2O through (de)nitrification processes in manure (Gerber et al., 2013; Scarborough et al., 2014). Because of this, the latter two GHGs account for 80% of the total agricultural GHGEs. In addition to GHGEs, a meat-based diet also puts pressure on the water supply as the production of feed needs large amounts of irrigation water (Chai et al., 2019).

However, it is important to recognize that various types of meat carry distinct levels of environmental impact (Rabès et al., 2020). For instance, ruminant species (e.g. cows, sheep, goats, etc.) have a higher carbon footprint than monogastric species (e.g. pigs, chickens, turkeys, etc.) (González-García et al., 2018). The reason behind this is that ruminant species, due to their specialized stomach (rumen), emit high CH_4 emissions formed during the enteric fermentation process. On the other hand, it is important to note that ruminant species can feed on grasslands where crops cannot grow, thus land can still be used for agricultural purposes (Oltjen & Beckett, 1996).

2.2.2. The vegetarian diet

Changing from an omnivorous diet to a more sustainable diet could enhance human health while also mitigating climate change and its impacts (González et al., 2020b). According to the Food and Agriculture Organization of the United Nations (FAO), sustainable diets can be defined as: "Those diets with low environmental impacts which contribute to food and nutrition security and healthy life for present and future generations. Sustainable diets are protective and respectful of biodiversity and ecosystems, culturally acceptable, accessible, economically fair and affordable; nutritionally adequate, safe and healthy; while optimizing natural and human resources."(*Food-Based Dietary Guidelines*, 2010). An important example of such a sustainable diet is a plant-based diet (Sabaté & Soret, 2014).

2.2.2.1. Health effects of the vegetarian diet

Besides the fact that all the vegetarian diets have one thing in common, namely the absence of meat, there are also some differences among them. For example, lacto-ovo-vegetarians eliminate meat, poultry and fish from their diet but do consume dairy products and eggs. On the other hand, pesco-vegetarians have a similar diet as lacto-ovo-vegetarians except for the fact that they also include fish in their meals (Olfert & Wattick, 2018). On the contrary, vegans exclude all foods of animal origin (Key et al., 1999).

Choosing one of these diets instead of a meat-based one might be the result of different incentives, including factors such as religion, health concerns, environmental reasons, animal welfare and others (Kim et al., 2022). For instance, according to Fox *et al*. (2008) approximately one-third of vegetarians make this choice particularly for their health (Fox & Ward, 2008). Indeed, opting for a vegetarian diet leads in several cases to a lower body mass index (BMI), lower cholesterol levels and fewer non-communicable diseases (e.g. T2DM) and thus consequently lower mortality in comparison to an omnivorous diet (Key et al., 1999; McEvoy et al., 2012). Vegetarians also tend to eat more fruits and vegetables, which results in less inflammation and oxidative stress (Butler, 2009). Apart from this, they also consume more whole grains and nuts and thus dietary fiber (Key, 1999). Additionally, they generally ingest fewer SFAs, trans-fatty acids and refined carbohydrates. This leads to lower body weight and thus lower chances of T2DM (Khazrai et al., 2014). Furthermore, vegetarians typically replace meat with other protein-rich foods such as soybeans. These contain, besides proteins, also high numbers of amino acids (e.g. lysine) and minerals (e.g. calcium and phosphate), which all increase insulin sensitivity and thus decrease the risk of T2DM (Olfert & Wattick, 2018). Finally, vegetarians experience a lower prevalence of CVD, as they consume more flavonoids or antioxidants that help in reducing blood clotting. However, although the absence of meat in a diet is associated with a lot of positive outcomes, it may also lead to several vitamin and mineral deficiencies such as vitamin B_{12}, zinc and iron. Moreover, according to the FAO meat, dairy and eggs are considered as an "essential source of nutrients" especially for some life stages such as pregnancy and childhood (FAO, 2023). Hence, since eliminating meat from the diet does not always result in a healthier lifestyle, vegetarians (as well as omnivores) should ensure to have a well-balanced diet with a variety of different foods (Craig, 2010).

2.2.2.2. Direct environmental effects of the vegetarian diet

Another important reason driving people to adopt a vegetarian diet, apart from its health benefits, is their concern for the environment (Fox & Ward, 2008). As elaborated in section 2.2.1.2, meat has a large impact on the environment. Therefore, several people choose to exclude this, as vegetarian diets seem to be more sustainable and have a lower carbon footprint than omnivore diets (González-García et al., 2018). However, it is important to look at the different meat substitutes, as they all have different impacts. For example, certain substitutes (e.g. imported cheese) might be even more of a burden for the environment, than when the meat is organically and locally produced. Another important factor is that animal-based foods need much more land than plant-based ones. This is mainly because animals need to be fed before they can be consumed, an action that requires additional crop production and thus land. Moreover, animal-based foods are produced less efficiently than plant-based ones, as the latter will directly convert solar energy to food energy. In addition to reduced land use and GHGEs, the vegetarian diet also scores better on water use when compared to the omnivore diet: producing one kilogram of plant-based protein necessitates about a hundred times less water than producing one kilogram of animal-based protein (Chai et al., 2019). On the other hand, according to Heller et al. (2021), nuts and seeds, which are consumed more by vegetarians than omnivores, have a higher water scarcity intensity (WSI) compared to meat. The WSI can be explained as: “the irrigation requirements per kg of food produced, characterized to reflect local water scarcity conditions.” (Heller et al., 2021).

To conclude, it is clear that to mitigate climate change and its impacts, a reduction in meat consumption should be made as plant-based diets have lower environmental impacts (Vettori et al., 2021). However, note that the complete elimination of meat is not realistic nor necessary as explained by the FAO (Clarys et al., 2014; FAO, 2023). Nonetheless, consumer preferences might lead to the elimination of meat and a switch to a vegetarian diet. Besides a reduction in the direct environmental impacts, this diet also decreases the indirect impacts (e.g. reduced risk of T2DM). Additionally, consumers could also change the type of meat included in their diet (e.g. poultry instead of beef) to reduce its environmental impact, as already explained in section 2.2.2.1. (Aleksandrowicz et al., 2016; Guinée et al., 2001).

2.3. Environmental Sustainability Assessment

As elaborated in section 2.2., there are a lot of direct and indirect environmental impacts associated with unhealthy diets, more specifically with a high intake of red meat. Therefore, it is important to provide consumers with clear and accurate information, which might lead to a shift to a more sustainable and healthy diet. There are different tools to estimate environmental impacts such as the environmental impact assessment for a region or a project, the Substance Flow Analysis for a substance flow over time or the life cycle assessment (LCA) (Guinée et al., 2001). The latter is most often used and discussed below.

2.3.1. Life cycle assessment

LCA is the most utilized method and will be used for this study. Furthermore, this method covers the entire life cycle of a product (good or service), from the extraction of raw materials to the production, distribution, usage, and waste phase (end-of-life or EoL) (Finnveden et al., 2009).

The LCA methodology is standardized by the International Organization for Standardization (ISO) (Heires, 2008). This ensures the quality and credibility of the process. Moreover, ISO 14040 and 14044 are standards that describe the framework and guidelines for conducting an LCA (Finnveden et al., 2009). As depicted in ***Figure 4**,* the methodology of LCA consists of four steps, which often need iteration (Bauer & Filho, 2004).

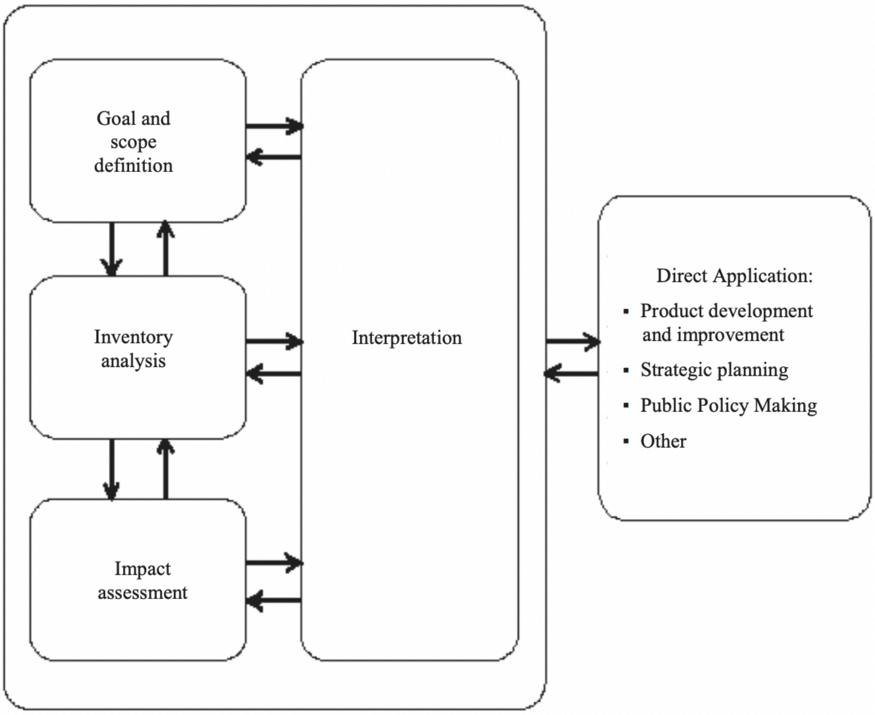

***Figure 4: The methodology of the life cycle assessment** (Bauer & Filho, 2004).*

During the first stage, the goal and scope must be defined. The goal defines the reason why the study is being conducted, the intended use and the target audience. The scope covers the system boundaries (temporal and spatial), the functional unit and the different impact categories (e.g. global warming, terrestrial toxicity, eutrophication, etc.). The system boundaries will define which processes are considered and for which data needs to be collected. Examples are cradle-to-grave, which includes the extraction of raw material till EoL, cradle-to-gate, which stops at the factory gate, gate-to-gate, etc. The choice of boundaries has a great influence on the final result as it might overlook important processes (Bauer & Filho, 2004). The functional unit serves as the reference flow against which the impact is evaluated and describes the function of the product (ISO 14044).

The second step of an LCA is the most time-consuming, which is the life cycle inventory (LCI). In this phase, all the inputs (raw materials, energy, etc.) and outputs (emissions, wastes, etc.) are quantified (ISO 14044). Because this step takes a lot of work, databases for various products were created (e.g. ecoinvent® database).

After the LCI, the data should be converted into the environmental impacts, which is called the life cycle impact assessment (LCIA). This step is subdivided into another four steps: classification of the different resources and emissions into the different environmental impact categories, characterization at the midpoint and endpoint level, and then finally the normalization and weighting. The normalization is conducted to illustrate the product's contribution to the global impact of a certain impact category. The weighting is done to quantify the most important impact categories. This results in having only one score, which can be seen as an advantage but also increases uncertainty (Jolliet et al., 2015).

In the final step of the LCA, the interpretation of the results from the preceding steps is done. It is important to thoroughly evaluate the chosen boundaries, functional unit and other assumptions. Finally, in some cases, uncertainty and sensitivity analyses are performed to verify the accuracy of the results. After this step, conclusions and recommendations can be made so improvements can be made (Jolliet et al., 2015).

In this manner, LCA could contribute to providing recommendations and information about the environmental consequences of different diets. This might lead to a shift in consumer behavior to a more sustainable diet. Consequently, this will result in a reduction of both direct and indirect environmental impacts (Vettori et al., 2021).

3. Objective

The aim of this master thesis was to quantify and compare the environmental and health effects of an omnivorous and a vegetarian diet within the Belgian context by performing an LCA. Specifically, this research delved into the direct environmental effects (related to dietary intake) of these diets, while also exploring the indirect environmental effects associated with their risk for T2DM (related to red meat intake). Furthermore, the research extends its focus to encompass the environmental impacts arising from the treatment and management of T2DM in Belgium. In addition, this study also examines the human health effects of both diets and T2DM by calculating disability-adjusted life years (DALYs), which is often used to quantify the burden of a certain disease. This combines the years lived with disability (YLD) with the years of life lost (YLL) due to premature mortality associated with the disease. This study thus intends to offer a comprehensive understanding of the environmental footprint associated with diets and possible health outcomes. By doing so, the consumers can gain a holistic view of the environmental implications of their dietary choices, potentially motivating them towards adopting a more sustainable diet. To the best of our knowledge, this is the first time that the direct environmental effects of different diets and those of their associated health effects (indirect effects) have been linked with each other, which emphasizes the importance of this study.

4. Methodology

The following chapter describes the steps that were taken to achieve the objectives mentioned in section 3. Moreover, the used methodology follows the standardized LCA framework, as described in section 2.3.1. First, the goal and scope of the research are defined. The latter covers the functional unit and system boundaries (Bauer & Filho, 2004). Secondly, the data inventory and complementary sources are described. Lastly, the chosen impact categories for the LCIA are presented.

4.1. Goal and scope

The goal of this study is to quantify the comprehensive environmental and health impacts (DALYs) of different diets by combining both their direct environmental effects (e.g. dietary intake) with the indirect effects, resulting from the risk of T2DM and its associated treatment (section 2.1.5.4).

For this research, a vegetarian and an omnivorous diet, both in a Belgian context, were compared with each other based on their environmental impacts. In addition, the association between red meat consumption and T2DM was considered, as the treatment of the latter has an environmental impact as well.

The results of this study can be used to inform consumers about the impact of their nutritional choices on the environment and their health. This could help motivate them to switch to a more sustainable diet. Additionally, this LCA was conducted following the ISO 14044 standard to enable comparison with other LCA outcomes.

4.1.1. Functional unit

The functional unit of this study is “the yearly dietary intake and treatment of type 2 diabetes mellitus linked to red meat consumption of 1000 Belgian adults”. The choice of 1000 over a single adult was made to enhance clarity and improve the comprehensibility of the final results.

4.1.2. System boundaries

A cradle-to-grave approach was chosen to achieve a full picture of the direct and indirect (e.g. due to T2DM) environmental impacts of both diets. This covers the entire life cycle, from the extraction of raw materials to the final disposal phase (EoL) (Bauer & Filho, 2004).

For both diets, the agricultural production, industrial processes, packaging and distribution to the retailers and end-consumer, and the consumer phase were considered, as shown in ***Figure 5*** (Cooreman-Algoed et al., 2024). Finally, the EoL of all food items (edible and inedible) throughout the entire food chain was also modeled based on Cooreman-Algoed *et al.* (2024).

For the treatment of T2DM, three scenarios were studied, which are elaborated in section 4.2. For each treatment, the production and packaging at the manufacturer, as well as the distribution and consumer phase of various treatment components to regulate the blood glucose levels (e.g. testing materials, medications used at home and/or doctors, etc.) were considered. Moreover, all packaging details were included unless specific information was unavailable (***Table 1***). In addition, the patient transportation to the pharmacy, GP, hospital, podiatrist and dietician were taken into account. Finally, the EoL at the end-consumer of the different elements was modeled *(**Figure 5*** and ***Figure 6***). As indicated in section 2.1.4. both physical exercise and other dietary changes (e.g. less sugar) are also important aspects of the T2DM prevention and treatment plan (Wu et al., 2014). However, due to a lack of information and specificity to the disease (Wilkins, 2020), both were excluded from this study.

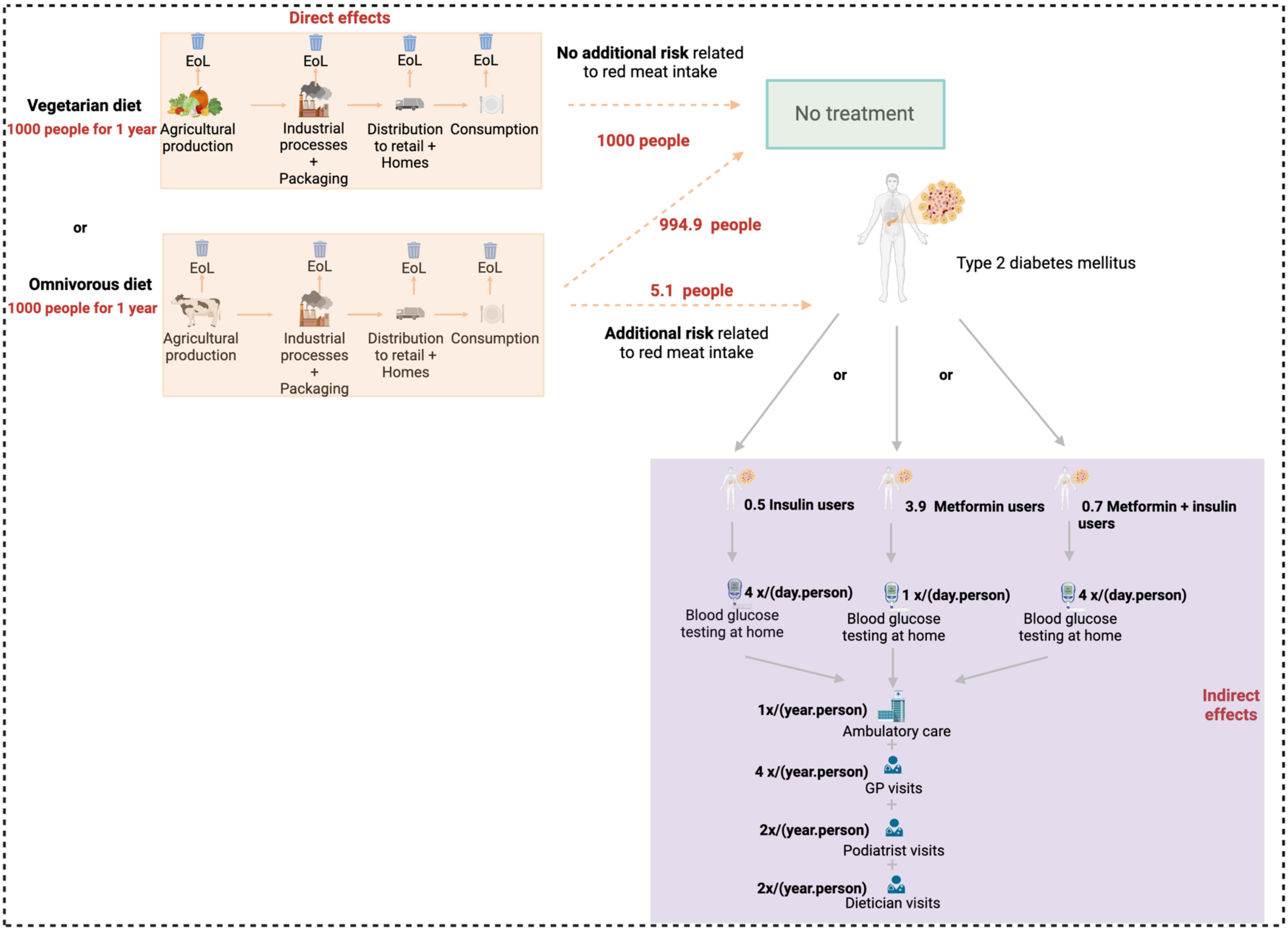

Figure 5: The direct and indirect environmental effects of a vegetarian and an omnivorous diet. *The dashed line indicates the system boundaries (Figure created in BioRender.com based on the content of Bruno et al. (2019) and Koeck et al. (2015)). Abbreviations: EoL, End-of-life; GP, general practitioner.*

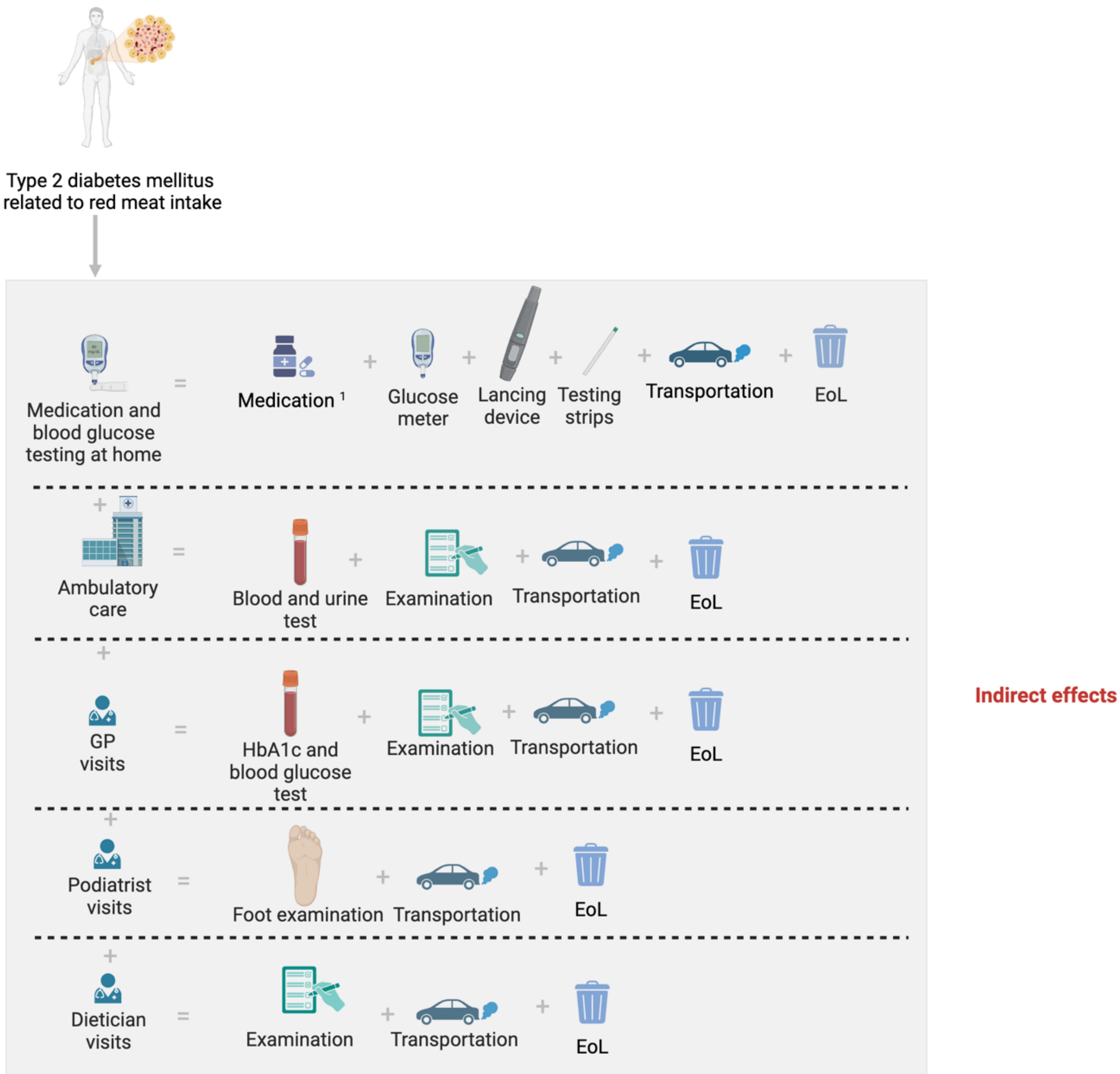

Figure 6: The different components of the health care treatment requirements of type 2 diabetes mellitus. *The treatment includes medication[1] and blood glucose testing at home, ambulatory care and visits to the GP, podiatrist and dietician. (Figure created in BioRender.com based on the content of Debaveye et al. (2019) and Koeck et al. (2015)). Abbreviations: GP, general practitioner; EoL, End-of-Life. [1] insulin, metformin or a combination of both.*

4.2. Life cycle inventory analysis and associated data sources

The following section describes the different steps and assumptions that were taken to obtain the LCI as well as the associated data sources to achieve this. Regarding the EoL of all components, secondary by-products generated during this stage, are recognized through the substitution of comparable products, using the system expansion approach.

4.2.1. Treatment of T2DM and its medical requirements

The following table (***Table 1***) describes the different data sources that were used for the LCI of the treatment of T2DM. Most of the inventory is based on Wilkins (2020) and then adjusted to the Belgian guidelines. However, some elements (e.g. consumer transport) were added to ensure consistency throughout the whole analysis. Wilkins (2020) describes the environmental impact of T2DM treatments in the United States (US) and in Sri Lanka. The former was selected as a reference for the composition and production processes of the different healthcare treatment elements (e.g. test strips) due to a lack of specific information in Belgium. Therefore, all the production processes (excl. pathology testing) and composition of the different components were based on Wilkins (2020) but adjusted to align with the Belgian guidelines regarding the T2DM healthcare pathway (Koeck et al., 2015).

Table 1: The different data sources used for the life cycle inventory of the treatment of type 2 diabetes mellitus. *Abbreviations: n/a, not applicable.*

	From cradle-to-care giver[1,3]	**Transport from producer to care giver [1,3]**	**Transport from pharmacy to consumer**	**Transport of patient to the care giver[2]**	**EoL**	**Extra packaging[5] when excluded in Wilkins (2020)**	**Pathology tests**
Metformin supply and use	Wilkins (2020)	Google maps (2024)	Cooreman-Algoed et al. (2023)	n/a	Based on expert knowledge	Cooreman-Algoed et al. (2023)	n/a
Insulin supply and use	Wilkins (2020) and Mattick et al. (2015)[6]	Google maps (2024)	Cooreman-Algoed et al. (2023)	n/a	Based on interview with T1DM patient	n/a	n/a
Glucose meter	Wilkins (2020)	Google maps (2024)	Cooreman-Algoed et al. (2023)	n/a	Based on interview with T1DM patient	n/a	n/a
Test strips	Wilkins (2020)	Google maps (2024)	Cooreman-Algoed et al. (2023)	n/a	Based on interview with T1DM patient	n/a	n/a
Lancet and lancing device	Wilkins (2020)	Google maps (2024)	Cooreman-Algoed et al. (2023)	n/a	Based on interview with T1DM patient	n/a	n/a
Ambulatory care[4]	Wilkins (2020)	Google maps (2024)	n/a	Debaveye et al. (2019)	Based on expert knowledge	n/a	McAlister et al. (2020-2021)

GP[4]	Wilkins (2020)	Google maps (2024)	n/a	Debaveye et al. (2019)	Based on expert knowledge	n/a	n/a
Podiatrist[4]	Wilkins (2020)	Google maps (2024)	n/a	Debaveye et al. (2019)	Based on expert knowledge	Not included	n/a
Dietician[4]	Wilkins (2020)	Google maps (2024)	n/a	Debaveye et al. (2019)	Based on expert knowledge	Not included	n/a

[1] To the pharmacy, GP, hospital, podiatrist or dietician.

[2] To the GP, hospital, podiatrist or dietician.

[3] The same producers as Wilkins (2020) were chosen for all the used elements. However, the production locations were adapted to sites closer to Belgium. Exception: for the alcohol swabs, paper covering the exam table, rubber gloves, HbA_{1C} testing cartridge and the foot exam filament, a different producer was chosen, as no specific producer was given by Wilkins (2020).

[4] The data inventory of the clinic visits from Wilkins (2020) was used. However, the clinic visit was subdivided into visits to the GP, hospital, podiatrist and dietician based on Belgian treatment guidelines. The different elements used during the clinic visit of Wilkins (2020) were then divided among the GP, hospital, podiatrist and dietician visits.

[5] All packaging was included except for the paper covering the exam table, rubber gloves, HbA_{1C} testing cartridge and the foot exam filament due to a lack of information.

[6] Regarding the insulin supply, tryptone was excluded from the inventory in Wilkins (2020). In the current research, this product was not found in the ecoinvent® 3.8 database, so soy hydrolysate was chosen as an alternative. Mattick *et al*. (2015) served as a source for the production process of soy hydrolysate.

To treat T2DM, metformin and insulin are commonly used medications (Drieskens et al., 2018; IMA, 2021). The former is typically prescribed when the glycemia is moderately elevated, whereas insulin is added to the treatment or taken individually when metformin alone cannot adequately control hyperglycemia (Mahler & Adler, 1999; Wu et al., 2014). According to Sciensano's health survey, 91.5% of diabetes (T1DM and T2DM) patients receive medication for their treatment. Among the T2DM patients using medication, 75.8% utilize oral antidiabetics (e.g. metformin), while 9.9% rely solely on insulin (Drieskens et al., 2018). Finally, the patient group that combines both medications (metformin and insulin), represents 14.3% of the T2DM patients (Droggen et al., 2013). The group that is not treated with medications is excluded from this study, as they only account for 8.5% of the T2DM patients (Drieskens et al., 2018). For each scenario, complications were not considered, as the focus lies on hyperglycemia. The following section describes all three scenarios along with their corresponding care pathways (***Figure 5***). The care pathway for the patient group that uses metformin in combination with insulin is the same as that of the insulin users (Koeck et al., 2015).

4.2.1.1. Metformin supply and use

The metformin users are assumed to take 2 pills of Metformin HCl Sandoz® 500 mg daily, as recommended by the T2DM guidelines and following Wilkins' approach (2020) (Koeck et al., 2015; Sandoz B.V., 2023). Patients that combine metformin with insulin, follow the same dosage recommendations. Based on the information gathered in multiple pharmacies in Antwerp, Sandoz appears to be the most common producer of metformin medication, hence its use in this study. While Wilkins (2020) did not include carton packaging of metformin, it was included in this study to stay consistent throughout the whole analysis. It was assumed to be similar to the cardboard packaging for vitamin B_{12} (Cooreman-Algoed et al., 2023).

Sandoz's extensive facility in Germany (Sandoz, 2023) is considered as metformin's production site in this study. The pills are then transported by truck to the pharmacies in Belgium, which is modeled by the distance from the production site to Brussels (*Google Maps*, 2024). The transport of the consumer to the pharmacy was set at 1.8 km, based on the findings of Cooreman-Algoed et al. (2023).

Finally, regarding the EoL phase of Metformin, only the disposal of packaging was considered: the carton box and blister pack were both recycled. The potential residues of the medication entering the sewer system were not taken into account for this study. It was also presumed that there were no losses during the production phase due to a lack of available information on this matter (Wilkins, 2020).

4.2.1.2. Insulin supply and use

Given its abundant use worldwide, Sanofi's Lantus Insulin Glargine was chosen as reference to model the insulin production and use (Wilkins, 2020). Insulin Glargine is a long-lasting insulin and is injected once daily (Sanofi, 2021). Moreover, this insulin is sold as single-use plastic insulin pens containing glass vials (Sanofi, 2021; Wilkins, 2020). Each pen contains 100 insulin units (U) and according to the guidelines, patients should start with 10 U per day (Lantus, 2023; Wilkins, 2020). The patients that use metformin in combination with insulin, inject the same amount. Furthermore, patients should always use a new needle and an alcohol swab for every injection. Important to note is that the pens should be refrigerated which was taken into account as well (Lantus, 2023).

Sanofi's production site is located in Germany, and it is assumed that the pens and needles are transported to the pharmacies in Belgium (Brussels) by refrigerated trucks (*Google Maps*, 2024; Lantus, 2023). Important to note, is that some components that are used during the insulin production process were not found in the used database. Therefore, an average impact per mass of all components needed to produce insulin was calculated for the components that occurred in small amounts (<2 grams). In addition, tryptone, which is used for insulin production was not included by Wilkins (2020) because of its absence in the database as well. Consequently, for this study, soy hydrolysate was chosen as a substitute, based on its similar production process (hydrolysis) (Sun, 2011; Wang et al., 2013). The inventory for this production is based on a study done by Mattick *et al.* (2015). However, the mass of NaOH and HCl (used to produce soy hydrolysate) was unknown and therefore not included in this study (Mattick et al., 2015).

For this study, Hartmann's alcohol swabs were chosen following a visit to a pharmacy in Antwerp, which confirmed their regular use. These swabs are produced in Xian'An, China and are transported to the largest harbor in Shanghai (Hartmann, 2024). From there, they are shipped to the harbor of Antwerp and subsequently delivered to the pharmacies in Belgium (Brussels) (*Google Maps*, 2024). Similar to the metformin scenario, a transport distance of 1.8 km to the end-consumer was considered (Cooreman-Algoed et al., 2023).

Lastly, the disposals of the carton packaging, alcohol swabs and insulin pens were taken into account. Based on an interview with a T1DM patient, it was assumed that the packaging was recycled, while the alcohol swabs and pens were incinerated with municipal house waste. The used needles must be disposed of in a designated needle container, which is then incinerated along with other hazardous waste (Medsdiposal, 2020). It was assumed that no losses occurred during insulin production (Wilkins, 2020) and the potential residues entering the sewer system were excluded from this study.

4.2.1.3. Self-testing

Diabetes patients must measure their blood glucose levels daily as part of managing this disease. The frequency of testing depends on their medication regimen. Patients using insulin injections or in combination with metformin are advised to make four measurements a day, while those solely on metformin test once daily (***Figure 5***) (DiabetesLiga, 2023a). Each test requires a glucose meter, lancing device, lancet and test strip. For this study, Abbott's Freestyle Lite meter was chosen as the glucose meter, similar to Wilkins (2020). According to the manufacturer, this device has an anticipated lifetime of five years and a battery life of 500 tests, which was adjusted according to the three scenarios. Abbott's lancing device has an expected lifespan of two years, whereas the lancet and test strips are single-use (Wilkins, 2020).

Abbott typically bundles all four items together as a package and therefore a single production site in the UK was considered. The products are transported by truck from the factory to Dover, shipped to Calais, and finally delivered to the pharmacies in Belgium (Brussels) by truck (*Google Maps*, 2024). As elaborated in section 4.2.1.1. final transport to the end-consumer (1.8 km) was taken into account as well (Cooreman-Algoed et al., 2023).

Data concerning the production processes was gathered from Wilkins's thesis (2020). However, according to the US guidelines, patients injecting insulin (or combining it with metformin) are required to test three times a day instead of four. Consequently, all self-testing data (e.g. number of test strips), was adjusted to align with the Belgian guidelines.

Regarding EoL management, the carton and plastic packaging were recycled, while the glucose meter, lancing device and test strips were incinerated among the municipal solid waste. The lancets have a similar disposal as the needles (section 4.2.1.2).

4.2.1.4. GP visits

According to the treatment guidelines, Belgian T2DM patients are advised to visit their GP four times a year. During visits, the patients are usually questioned about their diet, lifestyle, medication, etc. In addition, the GP performs a physical examination and measures their weight, height and blood pressure. Finally, their blood glucose levels and HbA_{1C} are measured (Koeck et al., 2015).

For the inventory only the items that are necessary for the blood test were taken into consideration. These include a glucose meter, lancing device, lancet, test strips, HbA_{1C} testing cartridge, rubber gloves, alcohol swabs, paper to cover the exam table and overhead energy use. The latter consists of power for the heating, ventilation and air-conditioning (HVAC) system, lighting, computer and HbA1c testing machine. On the contrary, the scale, blood pressure pump and computer (excl. energy) were excluded, given the fact that these are not specific to diabetes care and their extended use results in negligible impact (Wilkins, 2020). Data regarding all the used materials and energy is based on Wilkins's thesis (2020) but is adjusted to the Belgian guidelines.

Concerning transportation, the same locations for the glucose meter, lancing device, lancet, test strips and alcohol swabs are utilized, as discussed in section 4.2.1.2. and 4.2.1.3. In addition to these testing items, Abbott also produces HbA_{1C} testing cartridges, so the UK production facility was used again. For this study, it was assumed that the paper covering the table and rubber gloves were made by Medline, due to its prominent position in the distribution of medical supplies (Medline, 2021). Medline's manufacturing facility in France was chosen for this study. Direct transportation to the GP's office in Belgium (Brussels) by truck was presumed (*Google Maps*, 2024). Moreover, for the patient transportation to the GP, an average distance of 1.1 km by car was assumed (Debaveye et al., 2019b).

Finally, for disposal management, all materials were assumed to be incinerated as hazardous waste, while the packaging and paper inserts were recycled.

4.2.1.5. Ambulatory care

In addition to their regular GP visits, T2DM patients are advised to undergo an annual check-up with specialists at the hospital. According to the guidelines, during these appointments, patients will discuss their experience using the glucose meter, possible complications, concerns, etc. Afterward, their cholesterol, creatine and albumin-creatine ratio will be tested. Finally, a foot exam is performed to evaluate the possible risk for complications (Koeck et al., 2015).

The data regarding energy use and the foot exam, which includes alcohol swabs, paper covering the exam table, rubber gloves and foot exam filament is based on Wilkins (2020) and was adjusted to align with the Belgian guidelines (Koeck et al., 2015). The transportation and disposal management of these instruments is outlined in section 4.2.1.4. Medline was chosen as the manufacturer for the foot exam filament based on its ubiquity (section 4.2.1.4). It was assumed that the filament was delivered directly from France to the hospital in Belgium (Brussels) by truck.

On the other hand, all the materials necessary for the blood and urine tests are based on research regarding the environmental impact of pathology tests by McAlister *et al.* (2020-2021) (McAlister et al., 2020, 2021). The full blood analysis served as a reference for the cholesterol and creatin measurements, due to a lack of specific available data (McAlister et al., 2020). To measure the albumin-creatine ratio, the urine test was chosen as a reference (McAlister et al., 2021). For this study, Greiner Bio-One was chosen as the producer for all the materials needed for both tests due to its abundant use, according to experts (GP). Their manufacturing facility in Germany was slected for this study. Direct transportation by truck to the hospital in Brussels was assumed (*Google Maps*, 2024). Regarding patient transportation hospital an average distance of 10.9 km by car was assumed (Debaveye et al., 2019a).

Finally, all materials used during both tests were assumed to be incinerated as hazardous waste, while packaging materials were recycled.

4.2.1.6. Podiatrist and dietician visits

According to the guidelines, individuals with T2DM are eligible for reimbursement for two sessions with a podiatrist and two with a dietician annually (DiabetesLiga, 2020). Therefore, these sessions were incorporated into this study. During the podiatrist appointment, a foot exam is performed. The foot exam filament, paper on the exam table, rubber gloves and energy usage were the only aspects considered for this study. Their transportation and disposal details are elaborated in section 4.2.1.5.

During the visit to the dietician, the patient's weight and height are measured, followed by a discussion about their dietary habits. The scale and computer were not included here, due to their lengthy usage and therefore insignificant impact. Only energy use, which is similar to that of Wilkins (2020), was taken into account in this context. Given the limited information available, it was assumed that the patient's transportation to both the podiatrist and dietician is an average of the distances to the GP and hospital (6.0 km).

4.2.2. The vegetarian diet

The first examined diet in this study is the vegetarian diet. Unlike the omnivorous diet, it was assumed that vegetarians face no risk of T2DM related to red meat intake, as they do not consume any meat (Olfert & Wattick, 2018).

Data concerning the composition of the vegetarian diet was sourced from Clarys *et al.* (2014) and Cooreman-Algoed *et al*. (2024). Their study explored different diets (e.g. pescovegetarian, vegan, omnivorous, etc.) through a survey where the participants (> 20 years old) were questioned about their dietary consumption amounts (e.g. vegetables, pasta, etc.) and habits (e.g. omnivorous). Furthermore, the entire supply chain was considered including, food production, distribution and retail, consumption and EoL. Regarding the consumption phase, cooking and refrigeration were excluded from this study. However, food losses and waste (incl. inedible parts) throughout the entire food chain were incorporated, along with primary packaging (Cooreman-Algoed et al., 2024).

4.2.3. The omnivorous diet

The second diet under consideration is the omnivorous diet. First, daily dietary intake of the same food groups consumed by vegetarians in the age class 60-64 years was retrieved from the Belgian Food Consumption Survey (BFCS) (2014-2015). This choice of age class was based on the rise in T2DM abundance occurring around the age of 45. Therefore, the upper limit of the age class was chosen in function of the available data (IMA, 2021).

Subsequently, the data regarding both diets was linked to the environmental impact categories results by multiplying all dietary intakes by the findings calculated by Cooreman-Algoed *et al.* (2024). Details regarding Cooreman-Algoed *et al.* (2024)'s data are elaborated in section 4.2.2. The results were then adjusted to align with the FU given in section 4.1.1. The table below describes the composition of the different food groups that were included in this study.

Table 2: The composition of different food groups of the vegetarian and omnivorous diet. *The vegetarian diet does not include meat products or fish.*

Food group	Composition
Meat products	Red meat, poultry, lunch meat, other (rabbit, organs)
Meat substitutes	Tofu, vegetarian burger, etc.
Fish	Fish, fish products, shellfish
Eggs	Eggs
Starchy food	Pasta, bread, potatoes, etc.
Vegetables	Cucumber, eggplant, etc.
Fruits	Apples, oranges, bananas, etc.
Nuts and seeds	Almonds, peanuts, cashews, etc.
Sweets	Candy, cookies, pastries, etc.
Beverages	Water, wine, beer, etc.
Dairy and alternatives	Milk, yoghurt, soya milk, etc.
Sauces and butter	Ketchup, mayonnaise, butter, etc.

4.2.3.1. Association between red meat intake and T2DM

To establish the association between red meat intake and T2DM, the population attributable fraction (PAF) was calculated, which is "the fraction of cases of a disease that is attributable to a certain exposure in the entire population". This was calculated based on Equation (1), listed below:

$$PAF = \frac{RR(x)-1}{RR(x)} \qquad (1)$$

x represents the current exposure level, in this case, the average habitual intake of red meat (including beef, pork, lamb and mutton). This was derived from the BFCS (2014-2015) for the age class 60 to 64 years old and resulted in 33.6 g/d. RR(x) (1.06) indicates the associated relative risk (RR), which was obtained from a non-linear dose-response function based on Kosasih *et al.* (2021).

To be able to quantify how much of the human health burden caused by T2DM (DALYs) is attributable to red meat intake, Equation (2) was used (Kosasih et al., 2021).

$$AB = B \times PAF \quad (2)$$

AB stands for attributable burden, B for the burden of disease (total DALYs of the patients caused by the disease itself) and PAF is the population-attributable fraction (Kosasih et al., 2021). The total $DALYs_{patient}$ for the age group 60-64 years old was achieved from the Belgium National Burden of Disease Study, with approximately 30% of the DALYs attributed to YLL and 70% of YLD (complications and treatment) (De Pauw et al., 2023).

Next, the total number of Belgian T2DM patients being treated with medications was divided by the total Belgian population (De Pauw et al., 2023; Eurostat, 2023) in the specified age class. The result was then multiplied by the PAF. This was adjusted to the chosen FU of 1000 persons, resulting in an estimate of 5.1 persons out of every 1000 having T2DM related to red meat intake.

As elaborated in section 4.2.1., 9.9%, 75.8% and 14.3% of T2DM patients use insulin, metformin or a combination, respectively. The percentages were then multiplied by the

5.1 persons to establish the association between red meat consumption and T2DM. This resulted in 0.5 patients for the insulin scenario, 3.8 for the metformin scenario and 0.7 for the combination group after rescaling. Finally, the inventory data of the three T2DM scenarios were then multiplied by 0.5, 3.8 and 0.7 for insulin, metformin and combination scenarios, respectively.

4.3. Life cycle impact assessment

In order to address the environmental concerns of the direct and indirect impacts of both diets, this study looked at all impact categories: acidification, climate change, freshwater ecotoxicity, particulate matter, eutrophication (marine, freshwater, terrestrial), human toxicity (cancer and noncancer), ionizing radiation, land use, ozone depletion, photochemical ozone formation, resource use (fossils, minerals and metals) and water use. Out of these, five midpoint indicators were chosen. Climate change (kg CO_2 eq.), water use (m^3 depriv.), land use (Pt), fossil resource use (MJ) and freshwater ecotoxicity (CTUe) were chosen based their significant relevance in LCA research on dietary impacts and health care systems (Drew et al., 2022; Kustar & Patino-Echeverri, 2021; March et al., 2021; van Dooren et al., 2018).

Next, the environmental human health impact was assessed by calculating the $DALYs_{climate\ change}$ for the diets and the treatment of T2DM. Integrating both midpoint as endpoint indicators enables a comprehensive analysis of the environmental impacts of dietary patterns. However, only the climate change impact was linked to the human health endpoint, due to time constraints. The Hierarchical perspective was chosen, as recommended by Debaveye *et al.* (2020) (Huijbregts et al., 2016). To comprehensively assess the overall human health impact stemming from the disease itself and its environmental effects, the $DALYs_{patient}$ (section 4.2.3.1.) were added to the $DALYs_{climate\ change}$ (Equation (3)).

$$DALYs_{total} = DALYs_{patient} + DALYs_{climate\ change} \quad (3)$$

For the impact assessment method, the Environmental Footprint (EF) 3.0 was selected due to the European recommendations (Directorate-General for Environment, 2021).

Long-term emissions were excluded, while infrastructure processes were included. The background processes were gathered from ecoinvent® 3.8 and Agribalyse® 3.0.1.0 databases. Unit processes were selected with a cut-off allocation.

4.4. Used software

The LCA of the two diets and treatment of T2DM were modeled using the SimaPro® 9.4.0.2 software.

5. Results and discussion

5.1. Environmental impact comparison between the omnivorous and vegetarian diet

The following section describes the direct and indirect (due to T2DM treatment) environmental effects of the omnivorous and vegetarian diet for five impact categories: climate change, water use, land use, fossil resource use and freshwater ecotoxicity. The table below shows the results of the five impact categories. The omnivorous diet has an overall higher impact, except for water usage where the vegetarian diet scores higher. Details regarding all impact categories are elaborated in section 5.1.1. to 5.1.5.

Table 3: The impacts of the omnivorous and vegetarian diet on climate change, water use, land use, fossil resource use and freshwater ecotoxicity. *Abbreviations: FU, functional unit.*

	Climate change (tonne CO_2 eq./FU)	Water use (m^3 depriv./FU)	Land use (Mpt/FU)	Fossil resource use (MJ/FU)	Freshwater ecotoxicity (MCTUe/FU)
Omnivorous diet	1469.9	2.4×10^6	83.2	1.7×10^7	47.6
Vegetarian diet	870.9	2.8×10^6	47.9	1.3×10^7	31.6

5.1.1. Climate change

Figure 7 A illustrates the impact of the vegetarian and omnivorous diets on the climate change impact indicator. First of all, the omnivorous diet (1469.9 tonne CO_2 eq./FU) exerts a 1.7 times higher impact on climate change than the vegetarian diet (870.9 tonne CO_2 eq./FU). This discrepancy is mainly attributable to meat products, as they account for 42.7% of the total impact of the omnivorous diet. In particular, the substantial contribution of meat products to the overall impact of climate change can be attributed to the substantial amount of GHGs emitted during livestock production. Moreover, ruminant species emit methane during digestion, while manure produces N_2O emissions. In addition, these animals have an extensive land requirement for grazing, contributing to deforestation and subsequent CO_2 emissions (Gerber et al., 2015; Scarborough et al., 2014). Upon closer examination of the latter (***Figure 7 B),*** unprocessed red meat (279.5 9 tonne CO_2 eq./FU) emerges as the primary contributor, followed by lunch meat (167.3 tonne CO_2 eq./FU) and processed red meat (95.9 tonne CO_2 eq./FU). The reduced environmental impacts associated with processed red meat and lunch meat compared to unprocessed red meat can partly be accounted to their lower daily intakes (13.2 g/(person.day) and 22.1 g/(person.day) respectively, compared to 33.6 g/(person.day) for unprocessed red meat). In addition, processed red meat (e.g. a hamburger) contains a certain amount of water and other additives, rather than being entirely composed of meat. Consequently, less meat is required to obtain the same amount as unprocessed meat, which could potentially explain the lower climate change impact. However, the difference between both diets extends beyond meat (and fish) consumption. Furthermore, the vegetarian diet includes a substantially higher intake (72.5 times more) of meat substitutes and therefore contributes more to climate change within the vegetarian diet than within the omnivorous diet. Additionally, vegetarians tend to consume 2.1 times more vegetables than omnivores, further influencing their share of the climate change indicator. Within the vegetarian diet then, starchy foods (e.g. pasta, bread, rice, etc.) tend to have a greater impact compared to other food groups, partly due to their relatively high intake (395.7 g/(person.day)). Moreover, rice cultivation for example, generates substantial methane emissions, due to the anaerobic conditions of its flooded fields (Wang et al., 2023). On the contrary, potatoes are considered a sustainable crop, since their production results in minimal emissions as explained by Jennings *et al.* (2020).

On the other hand, both diets show considerable climate change impacts for beverages (such as water, coffee and tea) and dairy (and its alternatives), constituting 15.2% and 9.5% of the omnivorous diet and 21.3% and 22.4% of the vegetarian diet, respectively. This can partly be because of their high daily consumption: an average of 253.1 g/(person.day) and 1427.5 g/(person.day) for dairy (and its alternatives) and beverages respectively, with water alone averaging 750.3 g/(person.day) for both diets. Since such large consumption of dairy also requires an enormous production, dairy products contribute to climate change substantially due to methane emissions from cattle and associated CO_2 and N_2O emissions as explained above (Scarborough et al., 2014). Note that collectively, dairy and red meat comprise 55% of the total global agriculture emissions (World Health Organization, 2023).

Furthermore, the indirect effects of the omnivorous diet (related to the treatment of T2DM) are about 5000 times smaller than the direct effects of the diet (***Figure 7 A).*** This can be explained by the fact that both diets encompass 1000 individuals, while the treatment for T2DM is only considered for 5.1 patients (section 4.2.3.1). More specifically, the latter has a total climate change impact of 0.3 tonnes of CO_2 equivalents/FU (***Figure 12 A****),* whereas the omnivorous diet (without the treatment of T2DM) has 1469.6 tonnes of CO_2 equivalents/FU. Therefore, the indirect effects only account for 0.02% of the total impact. Despite its minor impact compared to those of the food groups of the omnivorous diet, its magnitude range aligns with existing literature findings (Marsh et al., 2016). More details regarding the environmental impact of the treatment of T2DM are given in section 5.2.

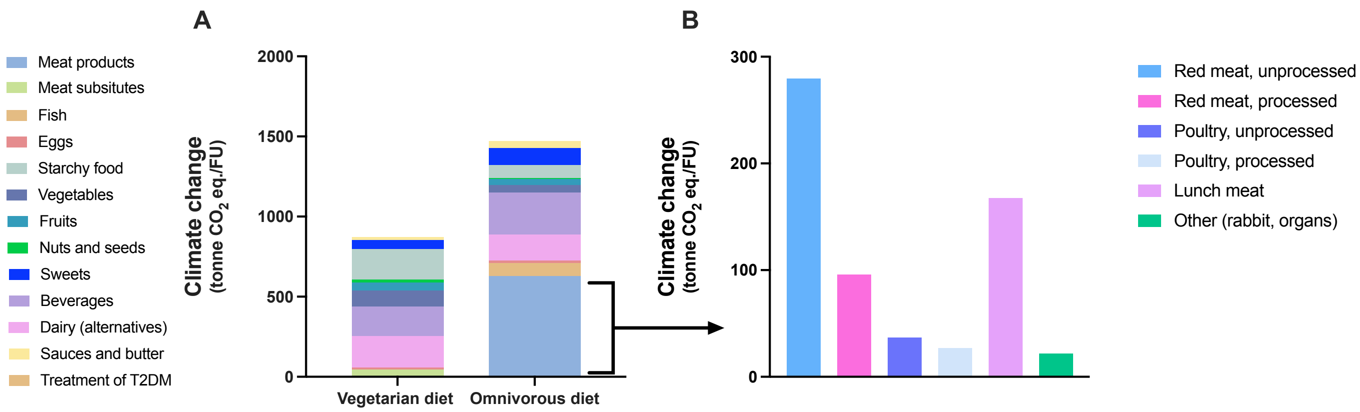

Figure 7: Climate change of the vegetarian and omnivorous diet. *(A)The whole diet and treatment of type 2 diabetes mellitus (B) A closer view of the meat products shown in (A). Abbreviations: FU, functional unit; T2DM, type 2 diabetes mellitus.*

5.1.2. Water use

A comparison of water usage between the two diets is shown in ***Figure 8 A.*** Surprisingly, contrary to the expectations based on studies from Chai *et al*. (2019) and Vettori *et al.* (2021), the vegetarian diet demonstrates a higher water usage impact (2.8 m^3 depriv./FU) than the omnivorous diet (2.4 m^3 depriv./FU) (***Figure 8 A).*** This is also in contradiction to the findings on climate change. The difference between these findings and those found by Chai *et al.* (2019), for example, is probably because water scarcity (m^3 depriv.) is included in this study, while the studies from the review of Chai *et al.* (2019) only consider water usage in m^3.

The impact on water use is rather high for both diets, which can predominantly be attributed to beverages (25.9% for the omnivorous diet and 29.6% for the vegetarian diet) and their high intake. Within the beverage group itself, fruit juice (e.g. orange juice) demonstrated the highest water use (43.7% for the omnivorous diet and 74.7% for the vegetarian diet). Several studies confirm this industry's water intensity (Esturo et al., 2023; Heller, 2017). In addition, since oranges consumed in Europe are primarily produced in Spain, they frequently suffer from severe drought conditions, exacerbating the industry's water scarcity issues (Joint Research Centre, 2024; Seminara et al., 2023). Furthermore, for the vegetarian diet specifically, fruits (19.4%), starchy foods (16.8%) and sweets (12.4%) also greatly influence water usage. For example, crop (e.g. rice, sugarcane, oranges, etc.) cultivation needs a large amount of water for irrigation (Belder et al., 2004; Heller, 2017). Similar to the vegetarian diet, fruits constitute an important portion (16.3%) of the total water use within the omnivorous diet.

Meanwhile, meat consumption accounts for 22% of the total water usage of the omnivorous diet. A similar trend can be seen as for the climate change indicator: unprocessed red meat is the biggest contributor again (23.3%), followed by lunch meat (18.1%) (***Figure 8 B).*** This finding is also confirmed by Suliman *et al*. (2024), who stated that the production of red meat accounts for 10.1% of the total water consumption for agricultural purposes (Suliman et al., 2024).

Lastly, in terms of water usage for treating T2DM, its impact is relatively minor (81.2 m^3 depriv./FU) compared to that of the omnivorous diet (without considering T2DM treatment) (2.4×10^6 m^3 depriv./FU). More details regarding water use for treating T2DM are given in section 5.3 (***Figure 13 A*****).**

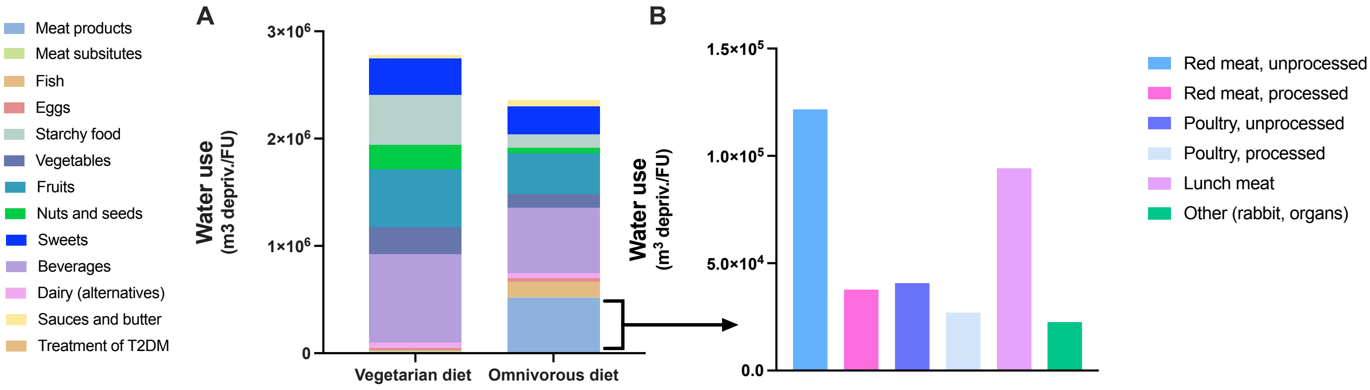

Figure 8: Water use of the vegetarian and omnivorous diet. *(A)The whole diet and treatment of type 2 diabetes mellitus (B) A closer view of the meat products shown in (A). Abbreviations: FU, functional unit; T2DM, type 2 diabetes mellitus.*

5.1.3. Land use

Figure 9 A depicts the land usage of the vegetarian and omnivorous diet. A similar pattern to that of climate change is apparent, wherein the omnivorous diet demonstrates a 1.7 times higher impact (83.2 Mpt/FU) compared to the vegetarian diet (47.9 Mpt/FU). In addition, meat consumption emerges again as the predominant contributor to the omnivorous diet, making up 50.1% of the total land use impact. Within the meat products (***Figure 9 B***), unprocessed red meat accounts for 45.6% (17.5 Mpt/FU) followed by lunch meat at 25.3% (9.7 Mpt/FU) and processed red meat at 15.4% (5.9 Mpt/FU), a trend similar to the climate change and water use indicators.

The dominance of meat products in land use, can be attributed to several factors. First of all, livestock animals require substantial amounts of feed, leading to extensive agricultural land requirements. In addition, these animals require land to graze and constructions for raising them. These requirements often contribute to deforestation and soil degradation(Chatti & Majeed, 2024). On the contrary, plant-based diets require less land due to their higher production efficiency, as explained in section 2.2.2.2 (Chai et al., 2019). However, it is essential to recognize that grassland, unfit for crop cultivation, can be used for grazing by cattle and other ruminant species, therefore adding value to agricultural production, as more land can be utilized (Oltjen & Beckett, 1996).

Furthermore, similar to previous impact categories, land use associated with treating T2DM is minimal (0.002 Mpt/FU) compared to the direct effects of the omnivorous diet. Specifics regarding land use for T2DM treatment are provided in section 5.3.3. (***Figure 14***).

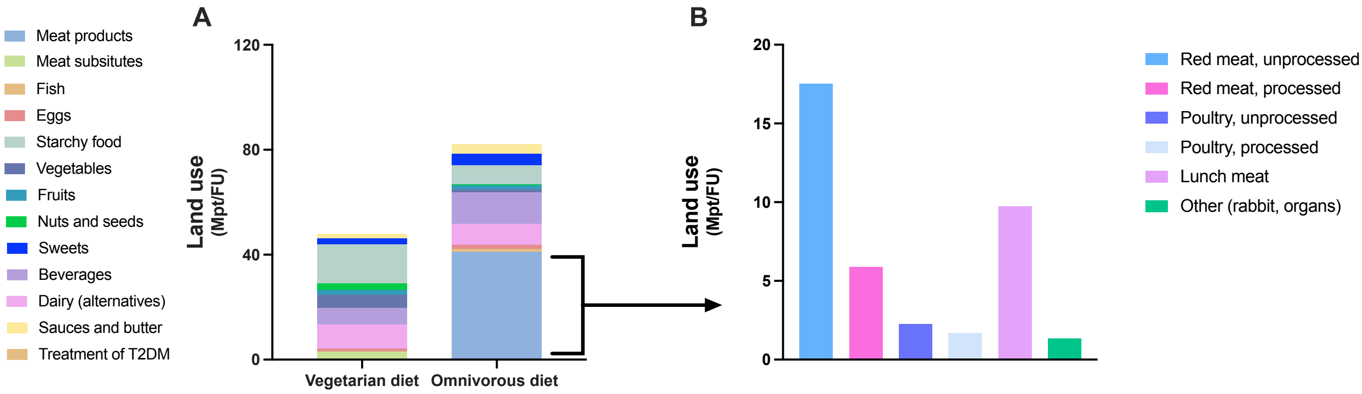

***Figure 9: Land use of the vegetarian and omnivorous diet**. (A)The whole diet and treatment of type 2 diabetes mellitus (B) A closer view of the meat products shown in (A). Abbreviations: FU, functional unit; T2DM, type 2 diabetes mellitus.*

5.1.4. Fossil resource use

The fossil resource utilization of both diets is shown in ***Figure 10 A,*** with the omnivorous diet showing a 1.3 times greater impact (1.7 x 10^7 MJ/FU) than the vegetarian diet (1.3 x 10^7 MJ/FU). In the case of the omnivorous diet, meat products are once again the highest contributor (35.1%) of fossil resource use. Moreover, in ***Figure 10 B,*** unprocessed red meat appears again as the predominant contributor (31.9%) compared to the other meat items, similar to the previously discussed impact categories.

Also, beverages play an important role in fossil resource use for both diets constituting 23.7% and 23.9% for the vegetarian and omnivorous diets, respectively. For the vegetarian diet, water (28.5%) and fruit juice (21.4%) stand out as the biggest contributors, while for the omnivorous diet, it is water (32.5%) and coffee (18.9%). Water and coffee have a relatively high daily intake compared to the other beverages (e.g. soft drinks), which partially explains their greater impacts. In addition, coffee's high impact is also due to the use of diesel for agricultural machinery involved in bean cultivation and production, while for water it is partly because of the packaging used for bottled water (e.g. PET).

Like previous impact categories, fossil resource consumption for treating T2DM is negligible (6403.9 MJ/FU) compared to the direct effects of the omnivorous diet. More details regarding fossil resource use for T2DM treatment are outlined in section 5.3.4. (***Figure 15***).

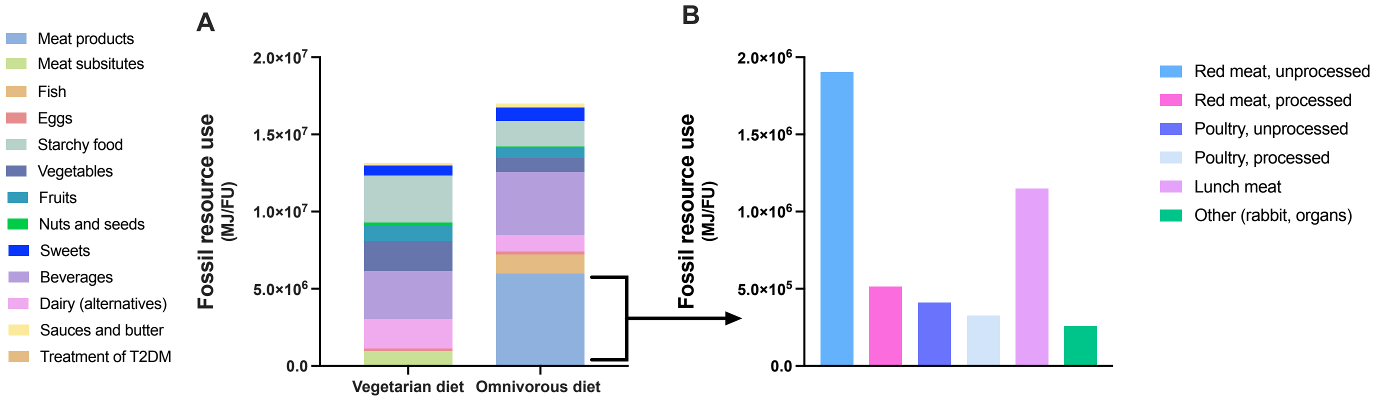

Figure 10: Fossil resource use of the vegetarian and omnivorous diet*. (A)The whole diet and treatment of type 2 diabetes mellitus (B) A closer view of the meat products shown in (A). Abbreviations: FU, functional unit; T2DM, type 2 diabetes mellitus.*

5.1.5. Freshwater ecotoxicity

For the freshwater ecotoxicity (***Figure 11***) a similar trend can be seen as for climate change, land use and fossil resource use: the omnivorous diet exhibits a higher freshwater ecotoxicity (47.6 MCTUe/FU) than the vegetarian diet (31.6 MCTUe/FU). In particular, meat products contribute 21.7% of the total freshwater ecotoxicity indicator of the omnivorous diet, with unprocessed red meat standing out with a freshwater ecotoxicity of 3.9 MCTUe/FU (***Figure 11 B*****).** A reason for the latter can potentially be the fact that the red meat industry affects freshwater ecosystems partly through runoff of nitrogen and phosphorus from manure (Bijay-Singh & Craswell, 2021).

When studying both diets, beverages play an important role, constituting 38.8% and 29.5% of the omnivorous and vegetarian diets respectively, partly due to their high intakes. More specifically, coffee and tea have the most substantial contribution to both diets, accounting for 26.5% and 15.4% for omnivorous and vegetarian diets, respectively. The high impact of coffee on freshwater ecotoxicity is likely because coffee can impact aquatic ecosystems through the release of waste and pesticides, leading to stress on living organisms (Fernandes et al., 2017).

Similar to the impact categories mentioned above, freshwater ecotoxicity linked to treating T2DM is minimal (0.003 MCTUe/FU) compared to the direct effects of the omnivorous diet. Additional information on freshwater ecotoxicity concerning T2DM treatment is given in section 5.3.5. (***Figure 16***).

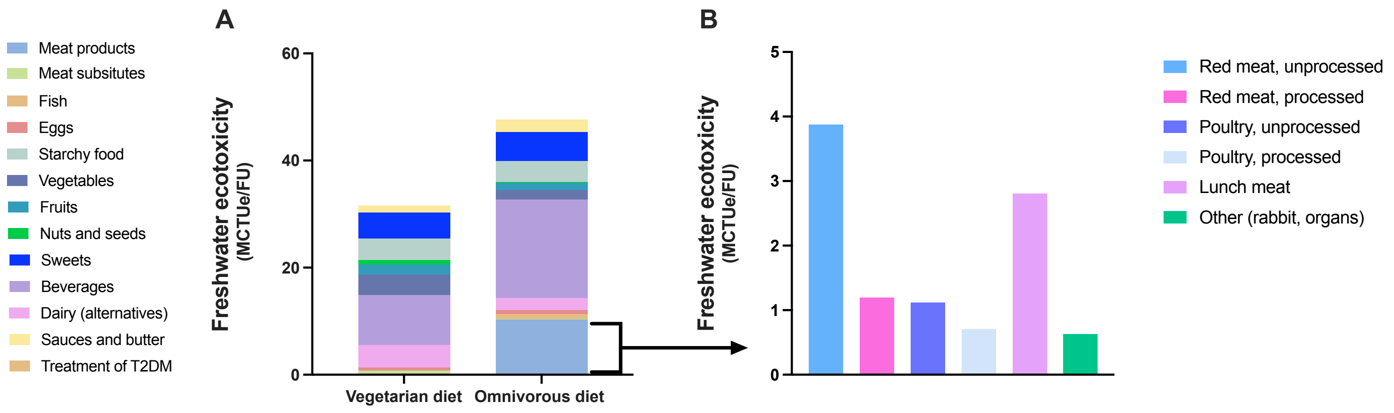

Figure 11: Freshwater ecotoxicity of the vegetarian and omnivorous diet. *(A)The whole diet and treatment of type 2 diabetes mellitus (B) A closer view of the meat products shown in (A). Abbreviations: FU, functional unit; T2DM, type 2 diabetes mellitus.*

5.1.6. The direct environmental impacts rescaled to reflect the T2DM patients

As explained in section 5.1.1. to 5.1.5., the treatment of T2DM (indirect effects) has a minor impact compared to the food groups of both diets (direct effects). However, when the direct impacts are adjusted to reflect those suffering from (and treated for) T2DM (5.1 patients) (***Figure 5***) instead of 1000 people, the indirect effects now constitute a larger portion of the difference between the total impacts (direct and indirect) of both diets. Detailed results of this are provided in ***Table 4***. Among the indirect effects of treating T2DM, fossil resource use shows the highest share (31.4%) within the (fossil resource use) impact difference between the omnivorous and vegetarian diet, followed by climate change (9.8%), freshwater ecotoxicity (6.0%), water use (3.9%) and lastly land use (1.0%). Although the shares of the indirect effects have increased, they are still rather low compared to the impacts of the different food items. Further details on the impacts of T2DM treatment are given in section 5.2.

Table 4: The shares of the indirect effects to the impact difference between the omnivorous and vegetarian diet. The direct effects were rescaled to reflect the people suffering from (and treated for) type 2 diabetes mellitus (T2DM) instead of 1000 people. *The direct effects are without the treatment for T2DM, and the indirect effects are due to treating T2DM. The vegetarian diet has a higher impact on water use than the omnivorous diet, thus here the difference was calculated by subtracting the omnivorous diet from the vegetarian diet.*

	Climate change (%)	Water use (%)	Land use (%)	Fossil resource use (%)	Freshwater ecotoxicity (%)
Share of indirect effects to the difference between the impacts of the omnivorous and vegetarian diet	9.8	3.9	1.0	31.4	6.0

5.2. Environmental impact comparison between different treatments for T2DM

The subsequent section outlines the environmental impact of the three treatment scenarios for T2DM. Five impact categories are elaborated: climate change, water use, land use, fossil resource use and freshwater ecotoxicity. ***Table 5*** presents the total impacts of the different scenarios per FU. When looking at the environmental impacts per FU, the metformin scenario is overall the highest contributor. For example, concerning climate change, it scores 3.4 and 2.2 times higher compared to insulin and combination users, respectively. However, it is important to stay critical when analyzing the results. Moreover, data concerning the number of patients within each treatment scenario (section 4.2.1.), is self-reported data and can thus be biased (e.g. elderly people using a lot of different medications, potentially making a mistake). On the other hand, as explained in section 1, one-third of the T2DM patients do not know they suffer from this disease (Sciensano, 2023), which leads to an underestimation, as this was not included in the study.

Table 5: The impacts of the different treatment scenarios for type 2 diabetes mellitus per functional unit. *Abbreviations: FU, functional unit.*

	Climate change (kg CO_2 eq./FU)	Water use (m^3 depriv./FU)	Land use (Pt/FU)	Fossil resource use (MJ/FU)	Freshwater ecotoxicity (CTUe/FU)
Insulin users	46.8	18.6	629.1	1176.8	1086.7
Metformin users	160.4	35.6	879.6	3563.5	3136.3
Combination users	72.4	26.9	803.7	1663.7	1598.4

In addition, to assess the effects of each scenario independently of the number of patients, the impacts were examined per person per year as well (***Table 6***). When looking at the impacts per person per year, the combination scenario is overall the highest contributor, as it scores the highest for all impact categories. For climate change, for example, it scores 1.9 and 1.2 times higher than the insulin and metformin scenarios, respectively. More details regarding each impact category are provided in sections 5.2.1. to 5.2.5.

Table 6: The impacts of the different treatment scenarios for type 2 diabetes mellitus per person per year.

	Climate change (kg CO_2eq./(person.year))	Water use (m^3depriv. /(person.year))	Land use (Pt /(person.year))	Fossil resource use (MJ /(person.year)	Freshwater ecotoxicity (CTUe /(person.year)
Insulin	98.6	30.2	1577.0	1630.9	1832.2
Metformin	61.3	10.8	288.5	1226.3	957.7
Combination	115.6	32.5	1620.6	1904.9	2053.9

5.2.1. Climate change

Figure 12 illustrates the climate change indicator for three treatment scenarios: insulin, metformin or a combination of both. Examining ***Figure 12 A*** reveals that metformin users have the highest climate change impact, constituting 57.4% of the total impact, primarily due to the high number of users (75.8%) within the metformin group, compared to the insulin users (9.9%) and combination users (14.3%). This notably affects the total impact, therefore, a more detailed picture is given in ***Figure 12 B***, where each treatment scenario is represented by a single patient.

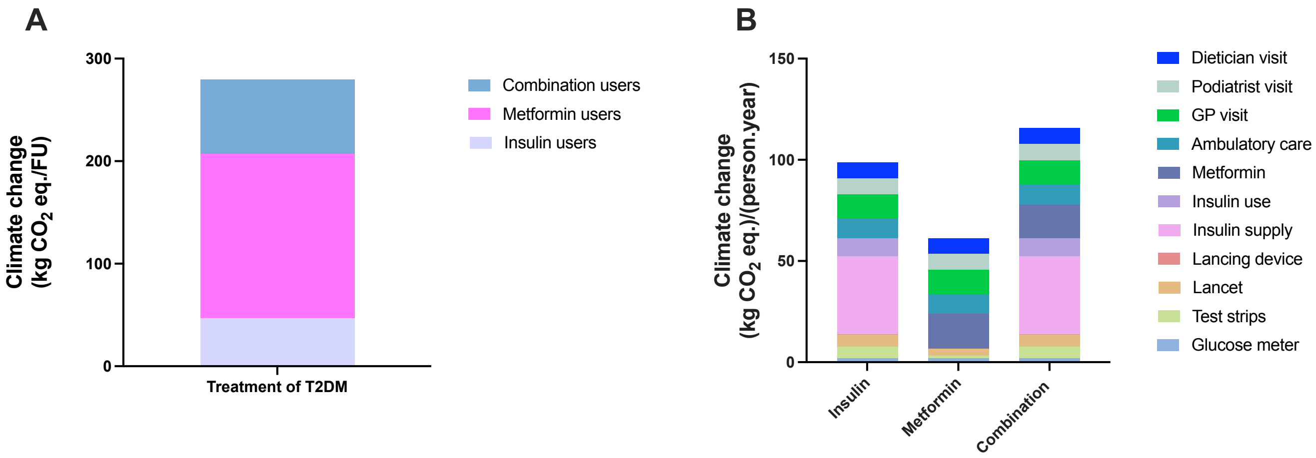

Figure 12: Climate change of the different treatment scenarios for type 2 diabetes mellitus. *(A) The share of the different scenarios per functional unit (B) A breakdown of the components used for the different scenarios per person per year. The entire life cycle of the different components (e.g. glucose meter) is shown. Abbreviations: FU, functional unit; GP, general practitioner; T2DM, type 2 diabetes mellitus.*

Table 7 provides a breakdown of the values of the various elements within each treatment scenario's care pathway, shown in ***Figure 12 B***. The combination scenario demonstrates the highest impact of 115.6 kg CO_2 eq./(person.year), followed by insulin (98.6 kg CO_2 eq./(person.year)) and metformin (61.3 kg CO_2 eq./(person.year)). This is because the combination group takes insulin as well as metformin so both production processes are considered here. Additionally, it was assumed that the doses of insulin and metformin for the combination treatment were the same as for the monotherapy. Therefore, when excluding metformin, the combination group's impact aligns with that of the insulin group, as an identical care pathway is assumed (section 4.2.1.). In these two scenarios, the insulin supply of the treatment accounts for the highest impact (38.5 kg CO_2 eq./(person.year)) (***Table 7***). When a closer look is taken at this component, electricity and tryptone (nutrient source for microbial growth (Hwang et al., 2016)) production, both used during the production phase, arise as the predominant contributors (Appendix B - Figure B-VII). Important to note is that as tryptone was not found in the ecoinvent® 3.8 database, soy hydrolysate was chosen as equivalent, as described in section 4.2.1.2. This might impact the final result, given their differences and considering tryptone's higher dosage compared to other compounds used during insulin production (e.g. urea, acetic acid, etc.). Moreover, the high impact of tryptone (soy hydrolysate) on climate change, is primarily due to the production of soybeans required for soy hydrolysate production (Appendix A – Table A-VII). The fact that the insulin supply accounts for the highest climate change impact, does not align with the results obtained by Wilkins (2020). This is because Wilkins (2020) did consider an alternative for tryptone and thus did not model this compound in their study.

Table 7: Climate change impact (kg CO_2 eq.)/(person.year) of the three type 2 diabetes mellitus (T2DM) treatment scenarios. *Self-testing materials (glucose meter, test strips, lancet, lancing device), medication (insulin and metformin) and different caregivers are included in the T2DM care pathway. Insulin supply is the entire life cycle of insulin production, without the use phase (e.g. insulin pen). Insulin use is the entire life cycle of the use phase of insulin (insulin pen, needle, alcohol swab). Abbreviations: GP, general practitioner.*

	Medication and self-testing							**Ambulatory care**	**GP visit**	**Podiatrist visit**	**Dietician visit**
	Glucose meter	Test strips	Lancet	Lancing device	Insulin supply	Insulin use	Metformin				
Insulin	1.9	5.9	5.9	0.2	38.5	8.7	0	9.7	12.1	7.9	7.8
Metformin	1.9	1.5	1.5	0.2	0	0	17.1	9.7	12.1	7.9	7.8
Combination	1.9	5.9	5.9	0.2	38.5	8.7	17.1	9.7	12.1	7.9	7.8

Interestingly, for the insulin (or combination) scenario, the insulin use phase has a relatively smaller impact (4.4 times) than the insulin supply (***Table 7****).* For the use phase, it is the transportation of the insulin pen to and from the pharmacy and the EoL (incineration) of the pen and alcohol swab that contributes the most to the climate change impact, followed by the production of the plastic casing of the pen and wrapper of the alcohol swab (Appendix B – Figure VIII). However, the fact that only car transport or no impact (e.g. walking) was included in this study for transportation to the pharmacy (Cooreman-Algoed et al., 2023), can impact the results as some might use public transport (Debaveye et al., 2019a).

Furthermore, the collective impact of the four caregivers (ambulatory care, GP, podiatrist and dietician) account for 38.1 %, 61.2% and 32.5% for the insulin, metformin and combination scenario, respectively. A closer examination reveals that transportation to the caregivers and the overhead energy constitute the majority of this impact (Appendix B – Figure B-X, Figure B-XI, Figure B-XII, Figure B-XIII). It is important to remember that this study exclusively considered car transportation for patient transport to the caregivers. This could thus influence the results, as some patients might opt for public transport instead of using their car (Debaveye et al., 2019a). In addition, this study assumed that all patients visit a dietician and podiatrist, which might not be the case in reality.

Regarding test strips and lancets, a clear difference is observed between the insulin (or combination) and metformin scenarios, attributed to the differences in the patient's self-testing frequency. Moreover, patients using insulin (alone or in combination with metformin) test four times a day, while those solely on metformin only once (section 4.2.1.3.), affecting the number of test strips and lancets used. Therefore, the impacts of both the test strips as the lancets of the insulin (or combination scenario) are 4.0 times higher than those of the combination scenario. However, it should be noted that, in reality, metformin users often test less than once a day (DiabetesLiga, 2023a), leading to an overestimation of these results.

Lastly, within the metformin scenario, the metformin component of the treatment accounts for 27.8% of the total climate change impact, with electricity usage during production representing the highest share (3.4 kg CO_2 eq./(person.year)) (Appendix B – Figure B-IX). Important to acknowledge, is that there are several processes possible to produce metformin, potentially affecting the final results (Wilkins, 2020). In addition, it is also worth noting that for this study the start dosage of both insulin as metformin were used as a reference. In reality, some patients might need higher doses, which could impact the results as well.

Table* 8** shows the shares of the five different healthcare elements within the T2DM care pathway (Figure 6***). The numbers indicate that the medication and self-testing component contributes the most (56.1%) to the total impact on climate change compared to the impacts of the different caregivers.

Table 8: The shares of the climate change impacts of the healthcare components within the type 2 diabetes mellitus care pathway. *Medication and self-testing include the glucose meter, test strips, lancet, lancing device, insulin supply and use, and metformin supply and use. An average of the three treatment scenarios (insulin, metformin and the combination of both) was taken. Abbreviations: GP, general practitioner.*

	Medication and self-testing (%)	Ambulatory care (%)	GP visit (%)	Podiatrist visit (%)	Dietician visit (%)
Average of the three scenarios	56.1	11.3	14.2	9.3	9.1

5.2.2. Water use

The second impact category is water use, which is depicted in ***Figure 13*** for the three treatment scenarios. Similar to the findings on climate change, the metformin scenario exerts the highest impact (35.6 m^3 depriv./FU), followed by the combination (26.9 m^3 depriv./FU) and insulin group (18.6 m^3 depriv./FU) (***Figure 13 A)***. However, when examining the results per single patient (***Figure 13 B)***, it is the combination scenario (32.5 m^3 depriv./FU) that leads, followed by the insulin (30.3 m^3 depriv./FU) and the metformin scenario (10.8 m^3 depriv./FU).

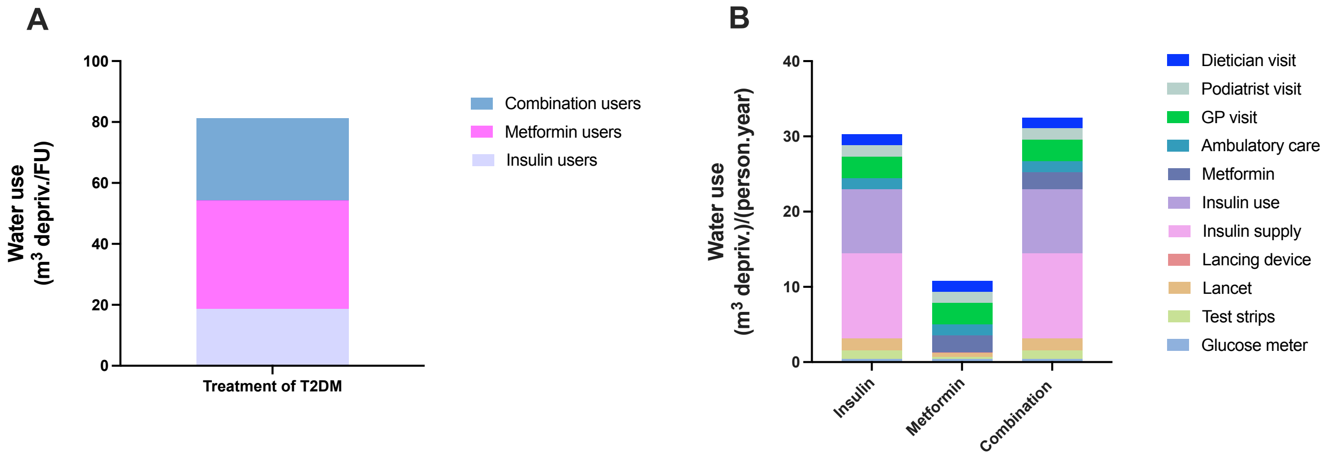

Figure 13: Water use of the different treatment scenarios for type 2 diabetes mellitus. *(A) The share of the different scenarios per functional unit (B) A breakdown of the components used for the different scenarios per person per year. The entire life cycle of the different components (e.g. glucose meter) is shown. Abbreviations: FU, functional unit; GP, general practitioner, T2DM, type 2 diabetes mellitus.*

Table 9 provides a breakdown of each component depicted in ***Figure 13 B.*** Furthermore, when analyzing the breakdown of the different components within the combination and insulin scenario, insulin supply and use collectively account for 65.5% of the overall impact on water use (***Table 9***). Concerning insulin use (Appendix B – Figure B-VIII), the production of cotton for the alcohol swab contributes the most. Cotton is known to be a drought-tolerant crop compared to other crops. However, since it is commonly cultivated in regions with limited or inconsistent rainfall, such as Xinjiang in China, it still heavily relies on irrigation for growth (Chapagain et al., 2006; Han & Jia, 2022; Mahmood et al., 2022). As for the insulin supply, the dipotassium phosphate (buffering agent to stabilize the pH level (Hwang et al., 2016)) and tryptone components are the highest contributors (Appendix B – Figure B-VII). This can partially be explained by the larger masses of these compounds used for the production compared to others such as EDTA and glycerin (Appendix A – Table A-VII).

Additionally, tryptone (soy hydrolysate) production consumes a large amount of water, which also accounts for its higher impact on water usage (Mattick et al., 2015).

Table 9: Water use (m^3 depriv.)/(person.year) of the three type 2 diabetes mellitus (T2DM) treatment scenarios. *Self-testing materials (glucose meter, test strips, lancet, lancing device), medication (insulin and metformin) and different caregivers are included in the T2DM care pathway. Insulin supply is the entire life cycle of insulin production, without the use phase (e.g. insulin pen). Insulin use is the entire life cycle of the use phase (e.g. insulin pen, alcohol swab, etc.). Abbreviations: GP, general practitioner.*

	Medication and self-testing							**Ambulatory care**	**GP visit**	**Podiatrist visit**	**Dietician visit**
	Glucose meter	Test strips	Lancet	Lancing device	Insulin supply	Insulin use	Metformin				
Insulin	0.4	1.1	1.6	0.03	11.3	8.5	0	1.5	2.9	1.5	1.4
Metformin	0.3	0.3	0.6	0.03	0	0	2.2	1.5	2.9	1.5	1.4
Combination	0.4	1.1	1.6	0.03	11.3	8.5	2.2	1.5	2.9	1.5	1.4

To summarize, the medication and self-testing component is the primary contributor (62.0 %) to the overall water use impact of the T2DM care pathway (***Table 10***), similar to the results for climate change.

Table 10: The shares of the water use impacts of the healthcare components within the type 2 diabetes mellitus care pathway. *Medication and self-testing include the glucose meter, test strips, lancet, lancing device, insulin supply and use, and metformin supply and use. An average of the three treatment scenarios (insulin, metformin and the combination of both) was taken. Abbreviations: GP, general practitioner.*

	Medication and self-testing (%)	**Ambulatory care (%)**	**GP visit (%)**	**Podiatrist visit (%)**	**Dietician visit (%)**
Average of the three scenarios	62.0	7.7	14.9	7.9	7.5

5.2.3. Land use

Figure 14 shows the impact of treating T2DM on land use. The metformin group exhibits the highest impact on land use, as it accounts for 38.0% of the overall impact, followed by the combination (34.8%) and insulin users (27.2%) **(*Figure 14 A)*.**

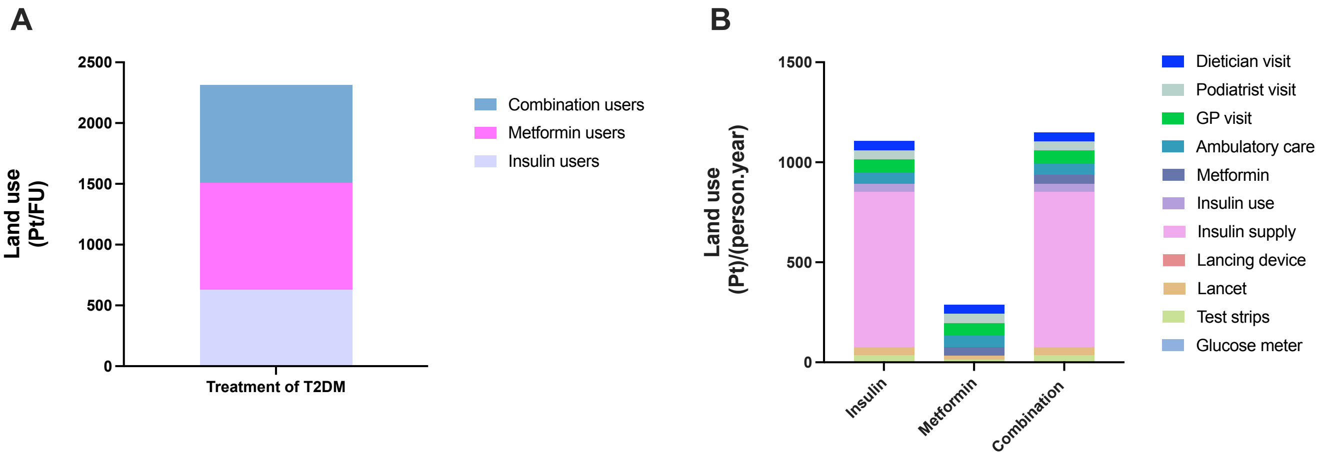

Figure 14: Land use of the different treatment scenarios for type 2 diabetes mellitus. *(A) The share of the different scenarios per functional unit (B) A breakdown of the components used for the different scenarios per person per year. The entire life cycle of the different components (e.g. glucose meter) is shown. Abbreviations: FU, functional unit; GP, general practitioner; T2DM, type 2 diabetes mellitus.*

Table 11 provides details on the impacts of the different components used in each treatment scenario. Concerning the insulin and combination scenarios, a similar trend can be seen as for the previous impact categories, as both show a substantially higher impact (5.5 and 5.6 times higher, respectively) than the metformin scenario (***Table 11***). Within both scenarios, the primary contributor is the production of yeast extract (nutrient source for microbial growth (Gusarov et al., 2015)) (Appendix B – Figure B-VII), used for the insulin supply, which accounts for 78.9% of the insulin scenario and 76.8% of the combination scenario.

Table 11: Land use (Pt)/(person.year) of the three type 2 diabetes mellitus (T2DM) treatment scenarios. *Self-testing materials (glucose meter, test strips, lancet, lancing device), medication (insulin and metformin) and different caregivers are included in the T2DM care pathway. Insulin supply is the entire life cycle of insulin production, without the use phase (e.g. insulin pen). Insulin use is the entire life cycle of the use phase (e.g. insulin pen, alcohol swab, etc.). Abbreviations: GP, general practitioner.*

	Medication and self-testing							**Ambulatory care**	**GP visit**	**Podiatrist visit**	**Dietician visit**
	Glucose meter	Test strip	Lancet	Lancing device	Insulin supply	Insulin use	Metformin				
Insulin	4.1	30.7	40.9	1.0	1245.4	42.6	0	55.6	64.9	46.5	45.3
Metformin	3.7	7.7	20.3	1.0	0	0	43.6	55.6	64.9	46.5	45.3
Combination	4.1	30.7	40.9	1.0	1245.4	42.6	43.6	55.6	64.9	46.5	45.3

Lastly, ***Table 12*** presents the percentages of the impacts of healthcare components in the T2DM care pathway, indicating that the medication and self-testing component contributes the most (66.7 %) to the impact on land use, which is similar to the previous impact categories.

Table 12: The shares of the land use impacts of the healthcare components within the type 2 diabetes mellitus care pathway. *Medication and self-testing include the glucose meter, test strips, lancet, lancing device, insulin supply and use, and metformin supply and use. An average of the three treatment scenarios (insulin, metformin and the combination of both) was taken. Abbreviations: GP, general practitioner.*

	Medication and self-testing (%)	Ambulatory care (%)	GP visit (%)	Podiatrist visit (%)	Dietician visit (%)
Average of the three scenarios	66.7	8.7	10.2	7.3	7.1

5.2.4. Fossil resource use

The fossil resource use of the three treatment scenarios is depicted in ***Figure 15***. Both ***Figure 15 A*** *and* ***Figure 15 B*** display similar trends to those observed for climate change and water use. Moreover, the metformin users show the highest overall impact at 55.6%, followed by the combination users at 25.9% and the insulin users at 18.4% (***Figure 15 A***). However, when considering treatments per patient, the combination scenario ranks the highest (***Figure 15 B).***

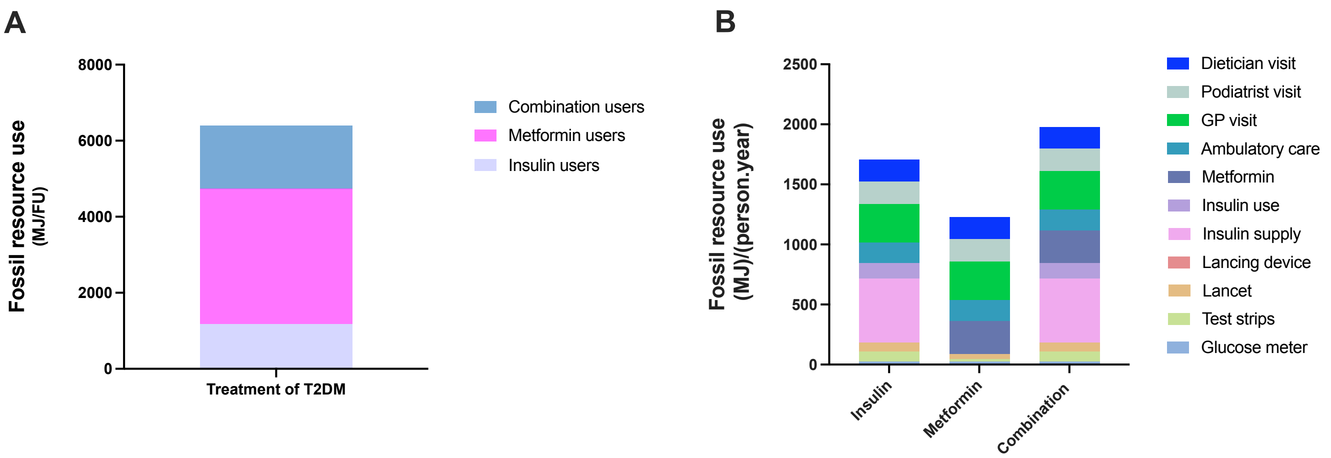

Figure 15: Fossil resource use of the different treatment scenarios for type 2 diabetes mellitus. *(A) The share of the different scenarios per functional unit (B) A breakdown of the components used for the different scenarios per person per year. The entire life cycle of the different components (e.g. glucose meter) is shown. Abbreviations: FU, Functional unit; GP, general practitioner; T2DM, type 2 diabetes mellitus.*

Table 13 provides a more detailed insight into the results of fossil resource use of each component within the treatment scenarios depicted in (***Figure 15 B).*** Across all three scenarios, visits to the dietician, podiatrist and GP, and ambulatory care, collectively contribute 50.6%, 70.3% and 43.6% to the insulin, metformin and combination scenarios, respectively. Furthermore, this impact is predominantly due to the overhead energy and transportation to the caregivers (Appendix B – Figure B-X, Figure B-XI, Figure B-XII, Figure B-XIII). Additionally, within the insulin and combination scenario, the insulin supply accounts for 31.1% and 26.8% of the total impact, mostly attributed to electricity use.

Table 13: Fossil resource use (MJ)/(person.year) of the three type 2 diabetes mellitus (T2DM) treatment scenarios. *Self-testing materials (glucose meter, test strips, lancet, lancing device), medication (insulin and metformin) and different caregivers are included in the T2DM care pathway. Insulin supply is the entire life cycle of insulin production, without the use phase (e.g. insulin pen). Insulin use is the entire life cycle of the use phase (e.g. insulin pen, alcohol swab, etc.). Abbreviations: GP, general practitioner.*

	Medication and self-testing							Ambulatory care	GP visit	Podiatrist visit	Dietician visit
	Glucose meter	Test strips	Lancet	Lancing device	Insulin supply	Insulin use	Metformin				
Insulin	24.1	82.2	76.2	2.9	455.6	127.6	0	172.5	320.8	185.7	183.3
Metformin	23.4	20.6	42.9	2.9	0	0	274.1	172.5	320.8	185.7	183.3
Combination	24.1	82.2	76.2	2.9	455.6	127.6	274.1	172.5	320.8	185.7	183.3

Finally, as shown in ***Table 14***, the proportions of the various healthcare components' impacts within the T2DM care pathway highlight the importance of medication and self-testing requirements to the overall impact on fossil resource use.

Table 14: The shares of the fossil resource use impacts of the healthcare components within the type 2 diabetes mellitus care pathway. *Medication and self-testing include the glucose meter, test strips, lancet, lancing device, insulin supply and use, and metformin supply and use. An average of the three treatment scenarios (insulin, metformin and the combination of both) was taken. Abbreviations: GP, general practitioner.*

	Medication and self-testing (%)	Ambulatory care (%)	GP visit (%)	Podiatrist visit (%)	Dietician visit (%)
Average of the three scenarios	43.9	11.2	20.9	12.1	11.9

5.2.5. Freshwater ecotoxicity

Figure 16 A, illustrates the final impact category, freshwater ecotoxicity, with the metformin scenario attributing to the highest share (53.8%). When considering scenarios per patient, the combination scenario once again demonstrates the highest impact with 2053.9 CTUe/(person.year) (***Figure 16 B)***.

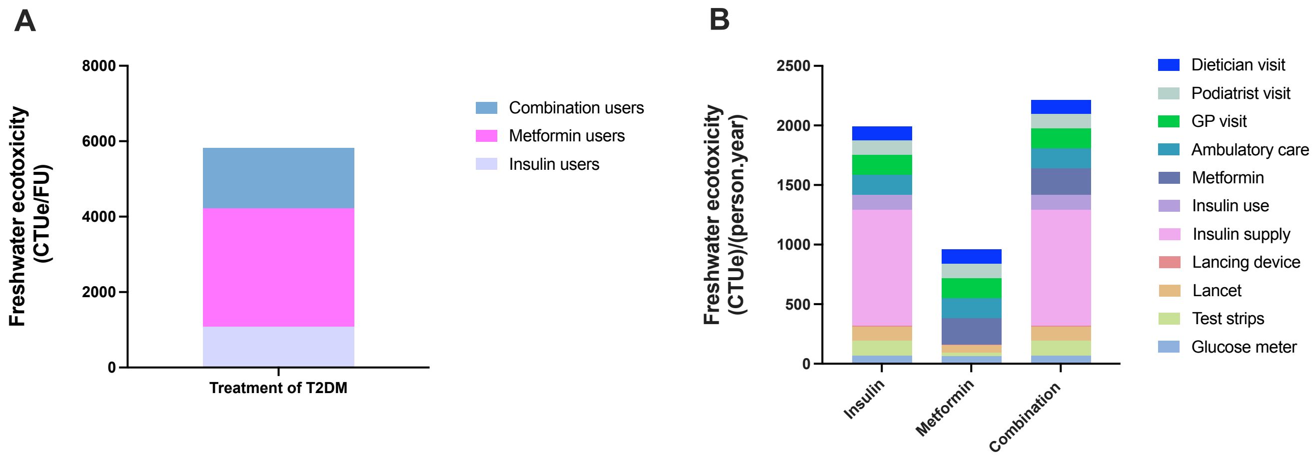

Figure 16: Freshwater ecotoxicity of the different treatment scenarios for type 2 diabetes mellitus. *(A) The share of the different scenarios per functional unit (B) A breakdown of the components used for the different scenarios per person per year. The entire life cycle of the different components (e.g. glucose meter) is shown. Abbreviations: FU, functional unit; GP, general practitioner; T2DM, type 2 diabetes mellitus.*

Further details on the various component results depicted in ***Figure 16 B*** are provided in ***Table 15***. Notably, it was anticipated that the metformin component would have a greater contribution, given its prevalence in aquatic systems as noted by Ambrosio-Albuquerque et al. (2021), who highlight its incomplete degradation by the human body. However, this study only accounts for the losses during the production of metformin potentially leading to an underestimation of its impact. As for the insulin and combination scenario, insulin supply accounts for 48.8% and 43.9% respectively (***Table 15***), with tryptone (soy hydrolysate) production showing the highest share (Appendix B – Figure B-VII). This can partially be explained by the fact that fertilizers used during the production process of soybeans can be released into the environment and harm aquatic systems (Bashir et al., 2020).

Table 15: Freshwater ecotoxicity (CTUe)/(person.year) of the three type 2 diabetes mellitus (T2DM) treatment scenarios. *Self-testing materials (glucose meter, test strips, lancet, lancing device), medication (insulin and metformin) and different caregivers are included in the T2DM care pathway. Insulin supply is the entire life cycle of insulin production, without the use phase (e.g. insulin pen). Insulin use is the entire life cycle of the use phase (e.g. insulin pen, alcohol swab, etc.). Abbreviations: GP, general practitioner.*

	Medication and self-testing							**Ambulatory care**	**GP visit**	**Podiatrist visit**	**Dietician visit**
	Glucose meter	Test strips	Lancet	Lancing device	Insulin supply	Insulin use	Metformin				
Insulin	68.6	124.8	119.0	3.9	811.6	127.3	0	168.6	167.1	123.3	117.9
Metformin	61.2	31.2	62.6	3.9	0	0	221.8	168.6	167.1	123.3	117.9
Combination	68.6	124.8	119.0	3.9	811.6	127.3	221.8	168.6	167.1	123.3	117.9

In conclusion, as depicted in ***Table 16***, the distribution of the different healthcare components in the T2DM care pathway shows that the key driver (60.0 %) of the overall freshwater ecotoxicity impact is the medication and self-testing component, which is a similar trend as seen in the previously mentioned impact categories.

Table 16: The shares of the freshwater ecotoxicity impacts of the healthcare components within the type 2 diabetes mellitus care pathway. *Medication and self-testing include the glucose meter, test strips, lancet, lancing device, insulin supply and use, and metformin supply and use. An average of the three treatment scenarios (insulin, metformin and the combination of both) was taken. Abbreviations: GP, general practitioner.*

	Medication and self-testing (%)	Ambulatory care (%)	GP visit (%)	Podiatrist visit (%)	Dietician visit (%)
Average of the three scenarios	60.0	11.7	11.6	8.5	8.2

5.3. The health impacts and the association between red meat intake and T2DM

Table 17 shows the results regarding section 4.2.3.1., which describes the association between T2DM and red meat. Specifically, among individuals aged 60 to 64, 5.5% of Belgian T2DM patients suffer from this disease because of red meat intake. In other words, 5.5% of the total $DALYs_{patient}$ of T2DM in Belgium is attributable to red meat intake. This results in 340.1 of $DALYs_{patient}$ and aligns with the results reported by Kosasih *et al.* (2021). These results are for the entire population of 60 to 64 years old in Belgium, that suffers from T2DM and undergoes treatment (with medication and/or follow a care program). However, the results concerning section 4.3., aligned with the FU, are provided in ***Table 18.***

Table 17: The attributable burden of type 2 diabetes mellitus related to red meat intake in Belgium. *Abbreviations: T2DM: type 2 diabetes mellitus, DALYs, disability-adjusted life years; PAF, population attributable fraction; AB, attributable burden.*

	Total $DALYs_{patient}$	PAF (%)	AB
T2DM (60-64 years old)	6163.7	5.5	340.1 of DALYs

When examining the results of ***Table 18,*** it is evident that the omnivorous diet yields 1.7 times more climate change DALYs compared to the vegetarian diet. In addition, the omnivorous diet exhibits 2.4 times more $DALYs_{total}$ than the vegetarian diet, as the latter does not entail $DALYs_{patient}$ associated with T2DM (related to red meat intake). Of the total DALYs (per FU) attributed to the omnivorous diet, 23.9% is linked directly to the human health burden of T2DM itself. Of the remaining 76.1%, which are the environmental DALYs, only 0.02% is attributed to treating T2DM. Consequently, it can be concluded that transitioning to a vegetarian diet would be advantageous for the global population, with even greater benefits for individuals with T2DM if they manage to prevent the onset of this disease.

Furthermore, given that this study only connects the climate change midpoint indicator to the human health endpoint, it is recommended that future studies include all midpoint indicators to ensure more accurate results. In addition, it should be noted that the $DALYs_{patient}$ include those caused by complications, while the environmental DALYs do not.

Table 18: The total disability-adjusted life years (DALYs) of the omnivorous and vegetarian diet per functional unit. *The $DALYs_{patient}$ due to type 2 diabetes mellitus (T2DM) itself are summed up with the $DALYs_{climate\ change}$ due to climate change of the diets and treatment for T2DM.*

	$DALYs_{patient}$	$DALYs_{climate\ change}$	$DALYs_{total}$
Omnivorous diet	0.4	1.4	1.9
Vegetarian diet	0	0.8	0.8

6. Conclusions and Future Perspectives

This thesis investigated the complex relationships between dietary choices, specifically omnivorous and vegetarian diets, and their environmental and health impacts within the Belgian context. Through a comparative LCA, this research highlights how these diets not only lead to direct environmental footprints through food production and consumption but also result in indirect environmental outcomes due to associated health risks, particularly T2DM and its treatment. This emphasizes the significance of this study, as, to our knowledge, such an analysis has not been done before.

As a result, omnivorous diets are associated with greater environmental burdens, exhibiting higher scores of climate change, land and fossil resource use and freshwater ecotoxicity compared to the vegetarian diet. Moreover, the omnivorous diet emits 1.7 times more kg CO_2 eq. per FU than the vegetarian diet, with 0.02% attributed to the treatment of T2DM. These environmental impacts arise predominantly (42.7%) from the direct requirements of agricultural practices for meat production, especially red meat. These practices are demanding in terms of land use and resource use and are major contributors to GHGEs. In addition, the treatment of T2DM accentuates these environmental impacts through the healthcare sector, substantially increasing the total environmental footprint of the omnivorous diet due to pharmaceutical use and healthcare visits. Even more remarkably, when the direct environmental impacts are readjusted to those suffering from (and treated for) T2DM, the indirect effects (related to treating T2DM), then account for 9.8% of the climate change impact difference between the omnivorous and vegetarian diets. In terms of the total DALYs per FU, the omnivorous diet scores 2.4 times higher than the vegetarian diet, with 23.9% directly related to suffering from T2DM and 76.1% due to environmental effects, of which 0.02% is attributed to treating T2DM. Nonetheless, it is important to mention that this research only investigated the association between red meat intake and T2DM, while consuming red meat is also directly linked to other diseases such as cancers and CVD (McAfee et al., 2010). The health implications (and indirect effects) of red meat consumption are thus underestimated.

Further analysis of T2DM treatment per FU reveals that metformin users exert the highest impact relative to the other two scenarios (insulin or combination), while the combination scenario scores higher across all impact categories at the individual patient level. The predominant contributor to the insulin and combination scenario is the insulin supply, specifically the energy and tryptone use. However, it is critical to acknowledge the substantial uncertainty regarding the production of tryptone, as this compound was not found in the ecoinvent® 3.8 database. Therefore, an alternative (soy hydrolysate) was chosen, possibly affecting the results. Besides the insulin supply, the visits to the caregivers also substantially impact climate change and fossil resource use, mainly because of overhead energy use and transportation. Overall, it can be concluded that the medication and self-testing component is the primary contributor to all impact categories, compared to visits to the four caregivers (***Figure 6***).

Conversely, the vegetarian diet demonstrates a relatively lower environmental impact, except in water usage where it uses 1.2 times more water than the omnivorous diet. The generally lower impact of vegetarians stems not only from reduced meat consumption but also from the fact that they have no additional risk for T2DM associated with red meat intake. Thus, these diets could play an important role in aligning dietary practices with broader sustainability goals by minimizing agricultural impacts and mitigating the demand for medical interventions. Also note that the total DALYs per FU of the vegetarian diet (0.8) are equal to the $DALYs_{climate\ change}$, as the $DALYs_{total}$ of the vegetarian diet do not include human health burdens caused by T2DM itself ($DALYs_{patient}$).

Future research should understand the limitations and uncertainties of this study to improve. First of all, this study only takes into account the patient group that is treated with medications. Thus, future studies could include a scenario of untreated patients, which might have higher impacts due to increased healthcare visits and possible complications or lower impacts when the disease is not too evolved. Moreover, this study did not include complications, as the focus was on controlling hyperglycemia. However, 30% of T2DM patients have complications at the moment of diagnosis (DiabetesLiga, 2023b), which could aggravate the environmental impacts associated with treatment so it could be interesting to include complications as well. Thirdly, extending the research scope to older populations beyond the 60-64 age range could be interesting, as T2DM incidence increases with age (Belga, 2024). Also, incorporating the one-third of patients who are unaware of their T2DM (Sciensano, 2023) could uncover further indirect environmental impacts due to their complications.

Besides enlarging the population of this study, it could also be useful to extend the analysis by looking at the association between T2DM and other food groups like processed meats in addition to red meat, as this might provide deeper insights into dietary impacts and inform more nuanced recommendations for dietary policy and public health interventions. Moreover, for this thesis, the frequency of self-testing and visits to the caregivers is based on guidelines provided by Koeck *et al*. (2015). However, working with real-life data in future studies could be insightful. Finally, by directly measuring the components of the healthcare pathway rather than relying on Wilkins (2020) and conducting a sensitivity analysis on tryptone and the frequency of visits to podiatrists and dieticians, the accuracy of the results could be enhanced.

In conclusion, the insights gained from this thesis provide a valuable resource for stakeholders, including consumers, healthcare professionals and policymakers to encourage a transition towards more sustainable, health-promoting dietary regimes in Belgium and more broadly.

7. Declaration of generative AI and AI-assisted technologies in the writing process

Throughout the working process of this thesis, Chat GPT 3.5 was used to improve the English language. Following the use of this tool, the content was reviewed and revised as necessary, while full responsibility for the content of this thesis was taken.

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Appendix A: Methodology

List of assumptions

Metformin supply and use

1. Patients take their pills daily without fail.
2. Patients do not suffer from any complications.
3. The US pathway is chosen as reference for the composition of the different healthcare treatment elements.
4. No losses occur during metformin production due to lack of information (Wilkins, 2020).
5. Metformin is sold in quantities of 270 pills per package.
6. 1 kg of plastic is assumed to be equivalent to 1 kg of recycled plastic.
7. To calculate the distance of the producer to the pharmacy, it is assumed that the pharmacy is located in Belgium, Brussels.
8. Only car transport or no impact (e.g. walking) are considered for the transportation to and from the pharmacy.

Insulin supply and use

1. Patients inject their insulin daily without fail.
2. Patients do not suffer from any complications.
3. Although insulin pens do not require refrigeration for up to 28 days, it is assumed they are refrigerated all year round (Wilkins, 2020).
4. Each pen contains 1 ml, which equals to 100 insulin units.
5. The density of water is used to calculate the weight of 1 ml of insulin.
6. Insulin pens are sold in packs of 10.
7. Entire pens are discarded as municipal waste.
8. A new needle is used for every injection.
9. A new alcohol swab is used for every injection.
10. Needles are disposed of in needle containers, which are available for free to diabetes patients at pharmacies.
11. The composition of the alcohol swabs as those used in Wilkins (2020) is the same as those used in this study.
12. The same brand as used in Wilkins (2020) is assumed.
13. Soy hydrolysate is used as an equivalent for tryptone.
14. To calculate the distance of the producer to the pharmacy, it is assumed that the pharmacy is located in Belgium, Brussels.
15. Only car transport or no impact (e.g. walking) are considered for the transportation to and from the pharmacy.

Glucose meter

1. The glucose meter has a lifetime of 5 years and is used by one person only.
2. Battery usage is adjusted based on the frequency of use in three different scenarios.
3. The same brand as used in Wilkins' study (2020) is assumed.
4. To calculate the distance of the producer to the pharmacy, it is assumed that the pharmacy is located in Belgium, Brussels.
5. Only car transport or no impact (e.g. walking) are considered for the transportation to and from the pharmacy.

Lancing device

1. The lifetime of the lancing device is 2 years and remains constant across all scenarios.
2. The lancing device is used by one person only.
3. The same brand as used in Wilkins' study is assumed.
4. To calculate the distance of the producer to the pharmacy, it is assumed that the pharmacy is located in Belgium, Brussels.
5. Only car transport or no impact (e.g. walking) are considered for the transportation to and from the pharmacy.

Lancet

1. A new lancet is used at each test.
2. Metformin users need one lancet per day.
3. Insulin users need four lancets per day.
4. Lancets are sold in packs of 200.
5. 1 kg of plastic is assumed to be equivalent to 1 kg of recycled plastic.
6. To calculate the distance of the producer to the pharmacy, it is assumed that the pharmacy is located in Belgium, Brussels.
7. Only car transport or no impact (e.g. walking) are considered for the transportation to and from the pharmacy.

Test strips

1. A new test strip is used at each test.
2. If specific enzymes or molecules are not available in the database, similar alternatives are chosen.
3. Metformin users need one test strip per day as they test once daily.
4. Insulin users need four test strips per day.
5. Test strips are sold in packs of 100.
6. 1 kg of plastic is assumed to be equivalent to 1 kg of recycled plastic.
7. To calculate the distance of the producer to the pharmacy, it is assumed that the pharmacy is located in Belgium, Brussels.

8. Only car transport or no impact (e.g. walking) are considered for the transportation to and from the pharmacy.

GP visit

1. Patients without complications have four doctor visits annually (Koeck et al., 2015).
2. Each appointment lasts 30 minutes.
3. To calculate the distance of the producer to the GP, it is assumed that the GP's office is located in Belgium, Brussels.
4. The overhead energy consumption for the hospital, doctor's office, podiatrist, and dietician are equal and similar to that of Wilkins (2020).
5. All patients go by car to the GP.
6. All medical waste is disposed as hazardous waste.

Ambulatory care

1. Annual hospital check-ups are assumed (Koeck et al., 2015).
2. One blood test is conducted.
3. To calculate the distance of the producer to the hospital, it is assumed that the hospital is located in Belgium, Brussels.
4. The overhead energy consumption for the hospital, doctor's office, podiatrist, and dietician are equal and similar to that of Wilkins (2020).
5. All patients go by car to the hospital.
6. All medical waste is disposed as hazardous waste.

Podiatrist and dietician visit

1. The average distance of hospital and doctor visits is used to calculate the distance to the podiatrist and dietician for the patient transport.
2. To calculate the distance of the producer to the podiatrist and dietician, it is assumed that their offices are located in Belgium, Brussels.
3. The overhead energy consumption for the hospital, doctor's office, podiatrist, and dietician are equal and similar to that of Wilkins (2020).
4. All patients go by car to the podiatrist and dietician.
5. All medical waste is disposed as hazardous waste.

Omnivorous and vegetarian diet

1. The Belgian diet is used as a reference for the omnivorous diet, which includes vegetarians and vegans as well as omnivores (Cooreman-Algoed et al., 2024).
2. The dietary habits of the vegetarian diet for those aged > 20 years are assumed to be the same as those for the 60-64 age group (Cooreman-Algoed et al., 2024).

The foreground and background systems

Table A-I: The foreground and background system of the treatment for type 2 diabetes mellitus. *Abbreviations: EoL, End-of-Life.*

	Foreground system	Background system
Number of patients in each treatment group	X	
Health care pathway	X	
Composition of health care pathway elements (e.g. glucose meter)	X	
Production process		X
Distribution within production phase		X
Distribution of product to caregiver	X	
Transport of patient	X	
Consumer phase	X	
EoL at consumer phase	X	

Table A-II: The foreground and background system of the vegetarian and omnivorous diet*. This table is based on Cooreman-Algoed (2024). Abbreviations: EoL, End-of-Life.*

	Foreground system	Background system
Diet composition	X	
Production process		X
Packaging		X
Distribution to retail		X
Consumer transport	X	
Food waste at home	X	
EoL of packaging	X	
EoL of food waste	X	
EoL during production process		X

Inventories of the healthcare treatment elements

Table A-III: Inventory of the glucose meter used to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year.*

Component Description	Measurement	Data Source	SimaPro Inventory Description
Circuit (g)	1.3	Wilkins (2020)	Integrated circuit, memory type {GLO}| market for | Cut-off, U
Screen (g)	0.7		Panel glass, for cathode ray tube display {GLO}| market for | Cut-off, U
Outer Case (g)	2.4		Injection moulding {RER}| processing | Cut-off, U Polypropylene, granulate {GLO}| market for | Cut-off, U
Circuit (Under Buttons) (g)	0.2		Integrated circuit, memory type {GLO}| market for | Cut-off, U
Metal Clip (g)	0.07		Brass {RoW}| market for brass | Cut-off, U Casting, brass {GLO}| market for | Cut-off, U
Small Metal Clip (g)	0.04		Brass {RoW}| market for brass | Cut-off, U Casting, brass {GLO}| market for | Cut-off, U
Plastic Cover (g)	0.03		Injection moulding {RER}| processing | Cut-off, U Polypropylene, granulate {GLO}| market for | Cut-off, U
Battery- Oral meds (g)	2.2	Wilkins (2020)	Battery cell, Li-ion {GLO}| market for | Cut-off, U
Battery- Insulin (g)	8.9		Battery cell, Li-ion {GLO}| market for | Cut-off, U
Packaging (g)	7.4	Wilkins (2020)	Carton board box production, with offset printing {GLO}| market for | Cut-off, U
Paper Insert (g)	21.2		Graphic paper, 100% recycled {GLO}| market for | Cut-off, U
Ship Transportation (tkm)	0.002	Google Maps (2024)	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U
Truck Transportation (tkm)	0.02		Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U

Car transportation (km)	0.2	Cooreman-Algoed et al. (2023)	Transport, passenger car {RER}| processing | Cut-off, U
Waste-Incineration (g)	31.8	Based on expert knowledge	Municipal solid waste {BE}| treatment of, incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U
Waste-Recyling (g)	28.6	Based on expert knowledge	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U

Table A-IV: Inventory of test strips used to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year.*

Component Description	Measurement (Insulin)	Measurement (Oral Meds)	Data Source	SimaPro Inventory Description
Base A (g)	88.3	22.1	Wilkins (2020)	Polyester resin, unsaturated {RER}| market for polyester resin, unsaturated | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Base B (g)	90.1	22.5		Polyester resin, unsaturated {RER}| market for polyester resin, unsaturated | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Glucose Oxidase Enzyme (g)	0.03	0.008		Enzymes {GLO}| market for enzymes | Cut-off, U
Co-Enzyme Flavine (g) Adenine Dinucleotide (g)	0.03	0.008		Enzymes {GLO}| market for enzymes | Cut-off, U
Mediator-Ferricyanide (g)	0.03	0.008		Sodium cyanide {RER}| market for sodium cyanide | Cut-off, U
Indicator-Silver (g)	0.03	0.008		Silver {GLO}| market for | Cut-off, U
Indicator-Carbon (g)	0.03	0.008		Carbon black {GLO}| market for | Cut-off, U

Plastic Tube Package (g)	3.2	0.8		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Cardboard Package (g)	1.6	0.4		Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
Transportation Ship (tkm)	0.007	0.002	Google Maps (2024)	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U
Transportation Truck (tkm)	0.08	0.02	Google Maps (2024)	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U
Transportation Car (km)	13.6	3.4	Cooreman-Algoed et al. (2023)	Transport, passenger car {RER}| processing | Cut-off, U
Waste-Incineration (g)	178.5	44.6	Based on expert knowledge	Municipal solid waste {BE}| treatment of, incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U
Waste-Recycling (paper) (g)	1.6	0.4	Based on expert knowledge	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U
Waste-Recycling (plastic) (g)	3.2	0.8	Based on expert knowledge	Polyethylene, high density, granulate, recycled {Europe without Switzerland}| polyethylene production, high density, granulate, recycled | Cut-off, U Polyethylene, high density, granulate {RER}| production | Cut-off, U Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U

Table A-V: Inventory of the lancets used to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year.*

Component Description	Measurement (Insulin)	Measurement (Orals)	Data Source	SimaPro Inventory Description
Needle (g)	332.9	83.2	Wilkins (2020)	Steel, unalloyed {RER}| steel production, converter, unalloyed | Cut-off, U Deep drawing, steel, 10000 kN press, automode {RER}| deep drawing, steel, 10000 kN press, automode | Cut-off, U
Plastic Casing (g)	690.5	172.6		Packaging film, low density polyethylene {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Packaging (g)	248.2	62.1		Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
Truck Transportation (tkm)	5.70E-01	1.4E-01	Google Maps (2024)	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U
Transportation Ship (tkm)	0.05	0.01	Google Maps (2024)	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U
Transportation Car (km)	6.8	1.7	Cooreman-Algoed et al. (2023)	Transport, passenger car {RER}| processing | Cut-off, U
Waste-Incineration (g)	3.3E+02	8.3E+01	Based on expert knowledge	Municipal solid waste {BE}| treatment of, incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U
Waste-Recycling (paper) (g)	2.4E+02	6.2E+01	Based on expert knowledge	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U

Waste-Recycling (plastic) (g)	6.9E+02	1.7E+02	Based on expert knowledge	Polyethylene, high density, granulate, recycled {Europe without Switzerland}| polyethylene production, high density, granulate, recycled | Cut-off, U Polyethylene, high density, granulate {RER}| production | Cut-off, U Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U

Table A-VI: Inventory of the lancing device used to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year.*

Component Description	Measurement	Data Source	SimaPro Inventory Description
Wheel (g)	0.3	Wilkins (2020)	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Outer Part-Back (g)	1.3		Injection moulding {RER}| processing | Cut-off, U Polyethylene, high density, granulate {GLO}| market for | Cut-off, U
Outer Part-Front (g)	1.3		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Protective Cover (g)	0.9		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Thumb Part-Female (g)	0.4		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Thumb Part-Male (g)	0.5		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Spring Container (g)	0.7		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Small Spring (g)	0.1		Steel, unalloyed {RER}| steel production, converter, unalloyed | Cut-off, U Wire drawing, steel {RER}| wire drawing, steel | Cut-off, U
Big Spring (g)	0.05		Steel, unalloyed {RER}| steel production, converter, unalloyed | Cut-off, U Wire drawing, steel {RER}| wire drawing, steel | Cut-off, U

Cardboard Package (g)	10.0	Wilkins (2020)	Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
Paper Insert (g)	3.0		Graphic paper, 100% recycled {GLO}| market for | Cut-off, U
Ship Transportation calais to dover (tkm)	0.0007	Google Maps (2024)	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U
Car Transportation (km)	0.5	Cooreman-Algoed et al. (2023)	Transport, passenger car {RER}| processing | Cut-off, U
Truck Transportation (tkm)	0.008	Google Maps (2024)	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U
Waste-incineration (g)	5.7	Based on expert knowledge	Municipal solid waste {BE}| treatment of, incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U
waste-recycline (paper) (g)	13.0	Based on expert knowledge	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U

Table A-VII: Inventory of the insulin supply to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year.*

Component Description	Measurement	Data Source	SimaPro Inventory Description
Energy Input-Natural Gas (MJ)	112.8	Wilkins (2020)	Heat, district or industrial, natural gas {DE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U

Energy Input – Electricity (MJ)	40.2		Electricity, medium voltage {DE}| market for | Cut-off, U
Energy Input-Steam (MJ)	12.7		Heat, from steam, in chemical industry {RER}| steam production, as energy carrier, in chemical industry | Cut-off, U
Tryptone (g) (soy hydrolysate)	1211.0		Soybean meal {GLO}| market for soybean meal | Cut-off, U Enzymes {GLO}| market for enzymes | Cut-off, U Water, ultrapure {RER}| market for water, ultrapure | Cut-off, U Heat, district or industrial, natural gas {DE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U
Yeast Extract (g)	605.5		Protein feed, 100% crude {GLO}| fodder yeast to generic market for protein feed | Cut-off, U
Sodium Chloride (g)	605.5		Sodium chloride, powder {GLO}| market for | Cut-off, U
Dipotassium phosphate (g)	605.5		Sodium phosphate {RER}| market for sodium phosphate | Cut-off, U
Water (g)	249.6		Water, ultrapure {RER}| market for water, ultrapure | Cut-off, U
Urea (g)	58.1		Urea {RER}| market for urea | Cut-off, U
Tris (g)	1.1		Unable to find a suitable equivalent in SimaPro.
EDTA (g)	0.04		EDTA, ethylenediaminetetraacetic acid {GLO}| market for | Cut-off, U
Dithiothreitol (reductant) (g)	0.2		Unable to find a suitable equivalent in SimaPro.
NaOH (g)	4.8		Sodium hydroxide, without water, in 50% solution state {GLO}| market for | Cut-off, U
Acetic Acid (g)	7.3		Acetic acid, without water, in 98% solution state {GLO}| market for | Cut-off, U
Trypsin (g)	0.4		Enzymes {GLO}| market for enzymes | Cut-off, U
Hypersil BDS C-18 (Sorbent) (g)	0.4		Activated silica {GLO}| market for | Cut-off, U
Citric Acid (g)	0.2		Citric acid {GLO}| market for | Cut-off, U
Zinc (g)	0.002		Zinc {GLO}| market for | Cut-off, U
Glycerine (g)	2.0		Glycerine {GLO}| market for | Cut-off, U

Metacresol (g)	0.3		Unable to find a suitable equivalent in SimaPro.
Cardboard Package (g)	25.8		Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
Glass Vial 10 ml (g)	73.6		Glass tube, borosilicate {GLO}| market for | Cut-off, U
Aluminum Top (g)	1.7		Aluminium, primary, ingot {RoW}| aluminium production, primary, ingot | Cut-off, U
Rubber Stopper on Top (g)	2.1		Seal, natural rubber based {DE}| production | Cut-off, U
Plastic Stopper (g)	0.7		Polyethylene terephthalate, granulate, bottle grade {GLO}| market for | Cut-off, U
Paper Insert (g)	13.0		Graphic paper, 100% recycled {GLO}| market for | Cut-off, U
Car Transport (km)	3.4	Cooreman-Algoed et al. (2023)	Transport, passenger car {RER}| processing | Cut-off, U
Refrigerated truck (tkm)	0.05	Google maps (2024)	Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO6, carbon dioxide, liquid refrigerant, cooling {GLO}| transport, reight, lorry with refrigeration machine, 3.5-7.5 ton, EURO6, carbon dioxide,liquid refrigerant, cooling | Cut-off, U
Waste-Incineration (g)	78.2	Based on expert knwolegde	Municipal solid waste {BE}| treatment of, incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas,conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U
Waste-Recycling (paper) (g)	38.8	Based on expert knwolegde	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U

Table A-VIII: Inventory of the insulin use to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year.*

Component Description	Measurement	Data Source	SimaPro Inventory Description
Pen Needle_ Plastic Casing (g)	352.2	Wilkins (2020)	Injection moulding {RER}| processing | Cut-off, U Polypropylene, granulate {GLO}| market for | Cut-off, U
Pen Needle_ Plastic Neck (g)	72.3		Injection moulding {RER}| processing | Cut-off, U Polypropylene, granulate {GLO}| market for | Cut-off, U
Pen Needle_Plastic Cover (g)	33.4		Injection moulding {RER}| processing | Cut-off, U Polypropylene, granulate {GLO}| market for | Cut-off, U
Pen Needle_Needle (g)	0.5		Steel, unalloyed {RER}| steel production, converter, unalloyed | Cut-off, U Wire drawing, steel {RER}| wire drawing, steel | Cut-off, U
Pen Needle_Seal (g)	15.8		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Aluminium, primary, ingot {RoW}| aluminium production, primary, ingot | Cut-off, U
Pen Needle_Cardboard Package (g)	62.1		Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
Pen Needle_ Car Transportation (km)	3.4	Cooreman-Algoed et al. (2023)	Transport, passenger car {RER}| processing | Cut-off, U
Pen Needle_ Truck Transportation (tkm)	0.2	Google Maps (2024)	Transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO6, carbon dioxide, liquid refrigerant, cooling {GLO}| transport, freight, lorry with refrigeration machine, 3.5-7.5 ton, EURO6, carbon dioxide, liquid refrigerant, cooling | Cut-off, U
Alcohol Swab_Cotton (g)	40.5	Wilkins (2020)	Textile, woven cotton {GLO}| market for | Cut-off, U
Alcohol Swab_Isopropyl Alchohol (ml)	54.5		Isopropanol {RER}| production | Cut-off, U
Alcohol Swab_Wrapper (g)	81.1		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Aluminium, primary, ingot {RoW}| aluminium production, primary, ingot | Cut-off, U Extrusion of plastic sheets and thermoforming, inline {RoW}| processing | Cut-off, U
Alcohol Swab _Cardboard Package (g)	51.7		Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U

Alcohol Swab_ Truck Transportation (tkm)	0.07	Google Maps (2024)	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U
Alcohol Swab _ ship Transportation (tkm)	0.7		Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U
Refrigeration (kWh)	3.1	Wilkins (2020)	Electricity, low voltage {BE}| market for | Cut-off, U
Waste-Incineration (g)	634.2	Based on expert knowledge	Municipal solid waste {BE}| treatment of, incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U
Transportation_Car (km)	1.7	Cooreman-Algoed et al. (2023)	Transport, passenger car {RER}| processing | Cut-off, U
Waste-Recycling (paper) (g)	113.7	Based on expert knowledge	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U
Waste_Inceineration (needles)	0.5		Hazardous waste, for incineration {Europe without Switzerland}| treatment of hazardous waste, hazardous waste incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U

Table A-IX: Inventory of the metformin supply and use to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year.*

Component Description	Measurement	Data Source	SimaPro Inventory Description
Natural Gas (MJ)	48.0	Wilkins (2020)	Heat, district or industrial, natural gas {DE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U
Electricity (MJ)	17.0		Electricity, medium voltage {DE}| market for | Cut-off, U
Steam (MJ)	5.0		Heat, from steam, in chemical industry {RER}| steam production, as energy carrier, in chemical industry | Cut-off, U

Dicyandiamide (g)	407.4		Dimethylacetamide {GLO}| market for | Cut-off, U
Dimethylamine Hydrochloride (g)	488.9		Dimethylamine {RER}| market for dimethylamine | Cut-off, U
Cyclohexanol (g)	162.9		Cyclohexanol {RER}| market for cyclohexanol | Cut-off, U
Ethanol (g)	206.2		Ethanol, without water, in 95% solution state, from fermentation {BR}| market for ethanol, without water, in 95% solution state, from fermentation | Cut-off, U
Package_cardboard (g)	127.8	Cooreman-Algoed et al. (2023)	Carton board box production, with offset printing {GLO}| market for | Cut-off, U
Package (g)	304.2	Wilkins (2020)	Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Truck Transportation (tkm)	1.5E+00	Google Maps (2024)	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U
Car Transport (km)	1.8E+00	Cooreman-Algoed et al. (2023)	Transport, passenger car {RER}| processing | Cut-off, U
Waste_Recycling (g)	1.2E+02	Based on expert knwoledge	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U
Waste- Recycling (plastic) (g)	304.2	Based on expert knwoledge	Polyethylene, high density, granulate, recycled {Europe without Switzerland}| polyethylene production, high density, granulate, recycled | Cut-off, U Polyethylene, high density, granulate {RER}| production | Cut-off, U Waste polyethylene, for recycling, sorted {Europe without Switzerland}| treatment of waste polyethylene, for recycling, unsorted, sorting | Cut-off, U

Table A-X: Inventory of ambulatory care to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year.*

Component Description	Measurement	Data Source	SimaPro Inventory Description
Transportation to Hospital (km)	21.8	Debaveye et al. (2019)	Transport, passenger car {RER}| processing | Cut-off, U
Alcohol Wipe_ Cotton (g)	0.1	Wilkins (2020)	Textile, woven cotton {GLO}| market for | Cut-off, U
Alcohol Wipe_ Isopropyl Alcohol (g)	5.0		Isopropanol {RER}| production | Cut-off, U
Alcohol Wipe_ Wrapper (g)	0.2		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Aluminium, primary, ingot {RoW}| aluminium production, primary, ingot | Cut-off, U Extrusion of plastic sheets and thermoforming, inline {RoW}| processing | Cut-off, U
Alcohol Wipe_ Cardboard Package (g)	0.1		Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
Paper on exam table (g)	6.5		Tissue paper {GLO}| market for | Cut-off, U
Foot Exam_ Filament (g)	0.5		Polyethylene terephthalate, granulate, bottle grade, recycled {RoW}| polyethylene terephthalate production, granulate, bottle grade, recycled | Cut-off, U Extrusion of plastic sheets and thermoforming, inline {RoW}| processing | Cut-off, U
Overhead Energy (kWh)	7.1		Electricity, medium voltage {BE}| market for | Cut-off, U
Waste-Incineration (g)	12.3	Based on expert knowledge	Hazardous waste, for incineration {Europe without Switzerland}| treatment of hazardous waste, hazardous waste incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U
Waste-Recycling (paper) (g)	0.1	Based on expert knowledge	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U

Transport truck_alcholswabs (tkm)	0.004	Google maps (2024)	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U
Transportshipe_alcohol swabs (tkm)	0.04	Google maps (2024)	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U

Table A-XI: Inventory of the phlebotomy done during the annual check-up to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year.*

Component Description	Measurement	Data Source	SimaPro Inventory Description
Rubber gloves (2 gloves) (g)	10.0	Wilkins (2020)	Acrylonitrile-butadiene-styrene copolymer {RER}| production | Cut-off, U Extrusion of plastic sheets and thermoforming, inline {RoW}| processing | Cut-off, U
Cotton swab (g)	0.5	*McAlister et al. (2020)*	Fibre, cotton {GLO}| market for fibre, cotton | Cut-off, U
Tube holder including needle (g)	2.9 1.5 0.1		Polypropylene, granulate {GLO}| market for | Cut-off, U Polyethylene terephthalate, granulate, bottle grade {GLO}| market for | Cut-off, U Steel, unalloyed {RER}| steel production, converter, unalloyed | Cut-off, U
Collection tube (g)	0.9 3.7 1.3		Polypropylene, granulate {GLO}| market for | Cut-off, U Polyethylene terephthalate, granulate, bottle grade {GLO}| market for | Cut-off, U Synthetic rubber {GLO}| market for | Cut-off, U
Pneumatic tube system (Wh)	1.2		Electricity, medium voltage {BE}| market for | Cut-off, U
Electricity (Wh)	1.2		Electricity, medium voltage {BE}| market for | Cut-off, U
Packaging (g)	0.4 0.1 1.7		Packaging film, low density polyethylene {GLO}| market for | Cut-off, U Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
Raegent (g)	0.0006 38.6		EDTA, ethylenediaminetetraacetic acid {GLO}| market for | Cut-off, U Water, ultrapure {RER}| market for water, ultrapure | Cut-off, U

Table A-XII: Inventory of the urine test done during the annual check-up to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year.*

Component Description	Measurement	Data Source	SimaPro Inventory Description
Specimen jar (g)	12.8	McAlister et al. (2021)	Polystyrene, expandable {GLO}| market for | Cut-off, U

Pipette (g)	1.0		Polypropylene, granulate {GLO}| market for | Cut-off, U
Ziploc bag (g)	0.9		Packaging film, low density polyethylene {GLO}| market for | Cut-off, U
Test tube (g)	4.0		Polypropylene, granulate {GLO}| market for | Cut-off, U
Electricity (Wh)	165.2		Electricity, medium voltage {BE}| market for | Cut-off, U
Compressed air (m3)	0.9		Compressed air, 600 kPa gauge {RER}| market for compressed air, 600 kPa gauge | Cut-off, U
Total transport of all tests (tkm) truck	0.03	*Google maps (2024)*	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U
Total transport of rubber gloves, paper and filament (tkm)	0.01		Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U
Waste- Incineration (all tests) (g)	40.0	*Based on expert knowledge*	Hazardous waste, for incineration {Europe without Switzerland}| treatment of hazardous waste, hazardous waste incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U
Waste-Recycling (paper) (g)	1.7	*Based on expert knowledge*	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U

Table A-XIII: Inventory of the visits to the general practitioner (GP) to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year. One patient visits their GP four times a year.*

Component Description	Measurement	Data Source	SimaPro Inventory Description
Transportation to Doctor's office	33.6	Debaveye et al. (2019)	Transport, passenger car {RER}| processing | Cut-off, U
Lancet_Needle (g)	3.5	Wilkins (2020)	Steel, unalloyed {RER}| steel production, converter, unalloyed | Cut-off, U Deep drawing, steel, 10000 kN press, automode {RER}| deep drawing, steel, 10000 kN press, automode | Cut-off, U
Lancet_ Plastic Case (g)	3.5		Packaging film, low density polyethylene {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Lancet_packaging (g)	2.6		Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
Lancing Device_Wheel (g)	7.9E+00		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Lancing Device_ Outer Part-Back (g)	0.0003		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Lancing Device_ Outer Part- Front (g)	0.0003		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Lancing Device_ Protective Cover (g)	0.0002		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Lancing Device_ Thumb Part- Female (g)	0.0001		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Lancing Device_ Thumb Part- Male (g)	0.0001		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Lancing Device_ Spring Container (g)	0.0002		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Lancing Device_ Small Spring (g)	2.6E-05		Steel, unalloyed {RER}| steel production, converter, unalloyed | Cut-off, U Wire drawing, steel {RER}| wire drawing, steel | Cut-off, U
Lancing Device_ Large Spring (g)	1.2E-05		Steel, unalloyed {RER}| steel production, converter, unalloyed | Cut-off, U Wire drawing, steel {RER}| wire drawing, steel | Cut-off, U

Lancing Device_packaging (g)	10.0		Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
Paper_insert (g)	3.0		Graphic paper, 100% recycled {GLO}| market for | Cut-off, U
Test Strip_ Base A (g)	0.2		Polyester resin, unsaturated {RER}| market for polyester resin, unsaturated | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Test Strip_ Base B (g)	0.2		Polyester resin, unsaturated {RER}| market for polyester resin, unsaturated | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Test Strip_ Glucose Oxidase Enzyme (g)	8.0E-05		Enzymes {GLO}| market for enzymes | Cut-off, U
Test Strip_Co-Enzyme Flavine Adenine Dinucleotide (g)	8.0E-05		Enzymes {GLO}| market for enzymes | Cut-off, U
Test Strip_ Mediator-Ferricyanide (g)	8.0E-05		Sodium cyanide {RER}| market for sodium cyanide | Cut-off, U
Test Strip_ Indicator-Silver (g)	8.0E-05		Silver {GLO}| market for | Cut-off, U
Test Strip_ Indicator-Carbon (g)	8.0E-05		Carbon black {GLO}| market for | Cut-off, U
Test Strip_plastic tube (g)	3.2		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Test Strip_packaging (g)	1.5		Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
Glucose Meter_ Circuit (g)	4.6E-07		Integrated circuit, memory type {GLO}| market for | Cut-off, U
Glucose Meter_ Screen (g)	2.5E-07		Panel glass, for cathode ray tube display {GLO}| market for | Cut-off, U
Glucose Meter_ Outer Case (g)	8.3E-07		Injection moulding {RER}| processing | Cut-off, U Polypropylene, granulate {GLO}| market for | Cut-off, U
Glucose Meter_ Circuit (under button) (g)	8.1E-08		Integrated circuit, memory type {GLO}| market for | Cut-off, U

Glucose Meter_ Metal Clip (g)	2.4E-08		Brass {RoW}| market for brass | Cut-off, U Casting, brass {GLO}| market for | Cut-off, U
Glucose Meter_ Small Metal Clip (g)	1.5E-08		Brass {RoW}| market for brass | Cut-off, U Casting, brass {GLO}| market for | Cut-off, U
Glucose Meter_ Plastic Cover (g)	1.2E-08		Injection moulding {RER}| processing | Cut-off, U Polypropylene, granulate {GLO}| market for | Cut-off, U
Glucose Meter_ Rubber Buttons (g)	6.7E-08		Synthetic rubber {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Glucose Meter_Battery (g)	0.02		Battery cell, Li-ion {GLO}| market for | Cut-off, U
Package (g)_glucosemeter	7.4		Carton board box production, with offset printing {GLO}| market for | Cut-off, U
Alcohol Wipe_ Cotton (g)	0.4		Textile, woven cotton {GLO}| market for | Cut-off, U
Alcohol Wipe_ Isopropyl Alcohol (g)	20.0		Isopropanol {RER}| production | Cut-off, U
Alcohol Wipe_ Wrapper (g)	0.9		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Aluminium, primary, ingot {RoW}| aluminium production, primary, ingot | Cut-off, U Extrusion of plastic sheets and thermoforming, inline {RoW}| processing | Cut-off, U
Alcohol Wipe_ Cardboard Package (g)	0.6		Folding boxboard carton {RER}| market for folding boxboard carton | Cut-off, U
HBa1c_Cartridge (g)	153.6		Polyethylene, high density, granulate {GLO}| market for | Cut-off, U Injection moulding {RER}| processing | Cut-off, U
Paper on exam table (g)	26.0		Tissue paper {GLO}| market for | Cut-off, U
Rubber Gloves (2 gloves) (g)	29.1		Acrylonitrile-butadiene-styrene copolymer {RER}| production | Cut-off, U Extrusion of plastic sheets and thermoforming, inline {RoW}| processing | Cut-off, U
Overhead Energy (kWh)	28.6		Electricity, medium voltage {BE}| market for | Cut-off, U

Waste-recycling (g)	23.7	Based on expert knowledge	Waste paperboard, sorted {Europe without Switzerland}| treatment of waste paperboard, unsorted, sorting | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, recycled | Cut-off, U Containerboard, fluting medium {RER}| containerboard production, fluting medium, semichemical | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, kraftliner | Cut-off, U Containerboard, linerboard {RER}| containerboard production, linerboard, testliner | Cut-off, U
Waste-Incineration (g)	2.5E+02	Based on expert knowledge	Hazardous waste, for incineration {Europe without Switzerland}| treatment of hazardous waste, hazardous waste incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U
Transport_Ship (voor Lancet, test strips, glucose meter, Hb1Ac) (tkm)	0.008	Google maps (2024)	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U
Transport_Truck (idem) (tkm)	0.08	Google maps (2024)	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U
Transport_Ship (alcohol swabs) (tkm)	0.2	Google maps (2024)	Transport, freight, sea, container ship {GLO}| transport, freight, sea, container ship | Cut-off, U
Transport_Truck (idem) (tkm)	0.02	Google maps (2024)	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U
Transport_Truck (papier, filament, Hb1Ac, gloves) (tkm)	0.04	Google maps (2024)	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U

Table A-XIV: Inventory of the visits to the podiatrist to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year. One patient visits their podiatrist twice a year.*

Component Description	Measurement	Data Source	SimaPro Inventory Description
Transportation to Doctor's office (km)	12.0	Debaveye et al. (2019)	Transport, passenger car {RER}| processing | Cut-off, U
Paper on exam table (g)	13.0		Tissue paper {GLO}| market for | Cut-off, U

Rubber Gloves (2 gloves) (g)	20.0	Wilkins (2020)	Acrylonitrile-butadiene-styrene copolymer {RER}| production | Cut-off, U Extrusion of plastic sheets and thermoforming, inline {RoW}| processing | Cut-off, U
Foot Exam_ Filament (g)	1.0		Polyethylene terephthalate, granulate, bottle grade, recycled {RoW}| polyethylene terephthalate production, granulate, bottle grade, recycled | Cut-off, U Extrusion of plastic sheets and thermoforming, inline {RoW}| processing | Cut-off, U
Overhead Energy (kWh)	14.2		Electricity, medium voltage {BE}| market for | Cut-off, U
Waste-Incineration (g)	34.0	Based on expert knowledge	Hazardous waste, for incineration {Europe without Switzerland}| treatment of hazardous waste, hazardous waste incineration | Cut-off, U Electricity, medium voltage {BE}| market for | Cut-off, U Heat, district or industrial, natural gas {BE}| heat and power co-generation, natural gas, conventional power plant, 100MW electrical | Cut-off, U Gravel, round {CH}| gravel and sand quarry operation | Cut-off, U
Transport_truck (tkm)	0.02	Google maps (2024)	Transport, freight, lorry 3.5-7.5 metric ton, EURO6 {RER}| transport, freight, lorry 3.5-7.5 metric ton, EURO6 | Cut-off, U

Table A-XV: Inventory of the visits to the dietician to manage type 2 diabetes mellitus. *This inventory shows the amounts for 1 patient for 1 year. One patient visits their dietician twice a year.*

Component description	Measurement	Data source	SimaPro Inventory Description
Overhead Energy (kWh)	14.2	Wilkins (2020)	Electricity, medium voltage {BE}| market for | Cut-off, U
Transport to office (km)	12.0	Debaveye et al. (2019)	Transport, passenger car {RER}| processing | Cut-off, U

Appendix B: Results and discussion

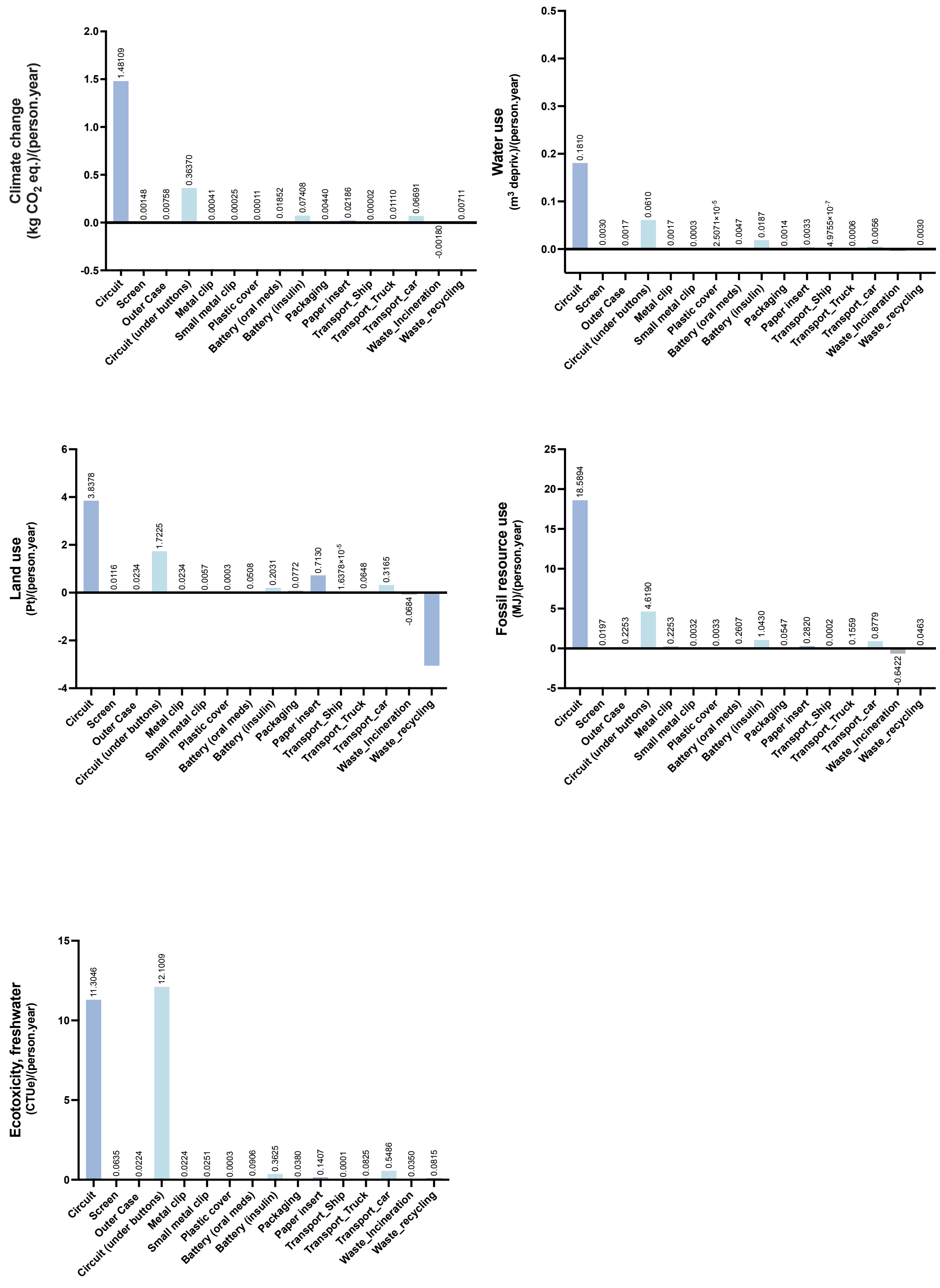


Figure B-I: The five investigated impact categories of the life cycle of the glucose meter.

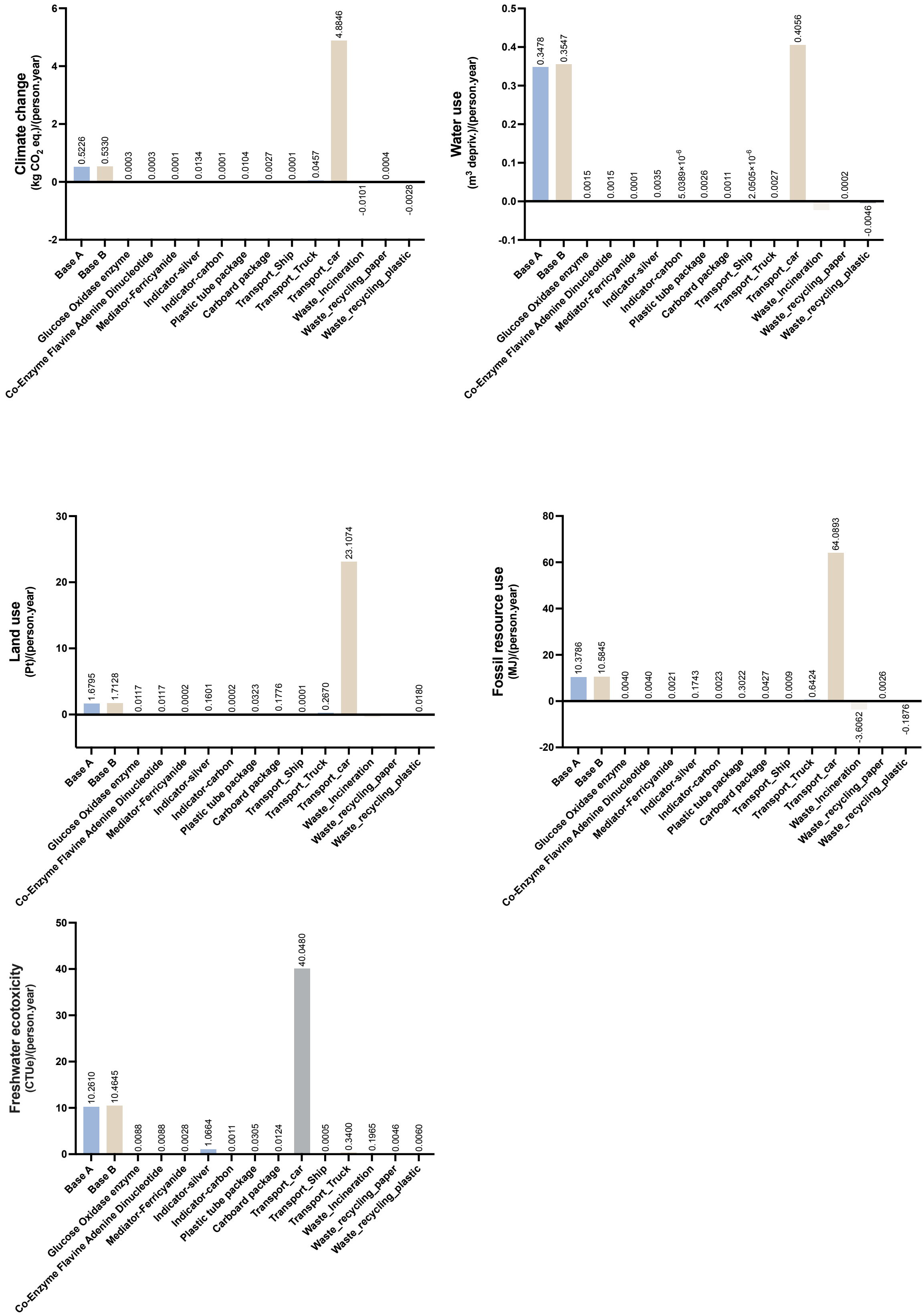


Figure B-II: The five investigated impact categories of the life cycle of the test strips for the insulin scenario (or in combination with metformin).

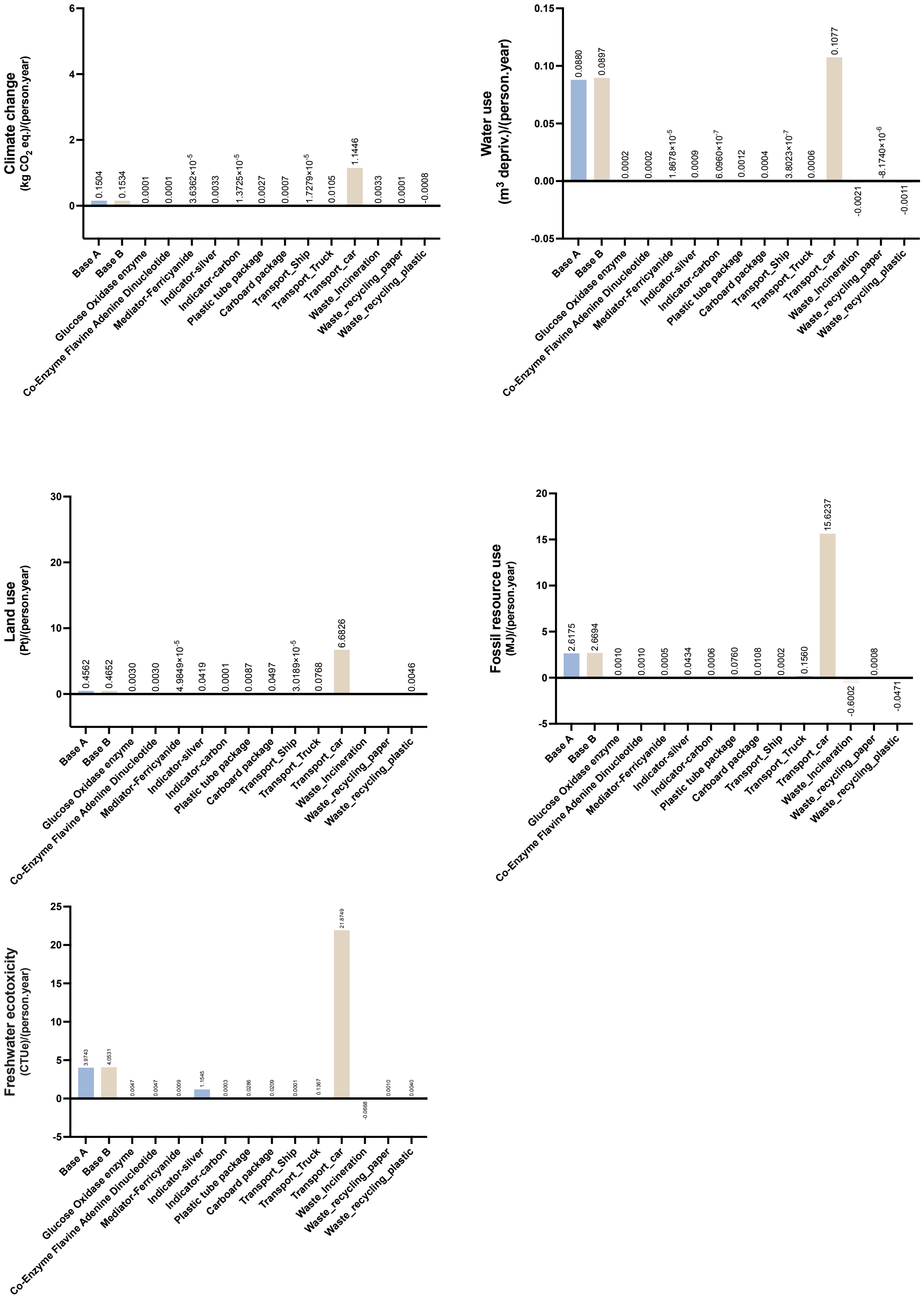


Figure B-III: The five investigated impact categories of the life cycle of the test strips for the metformin scenario.

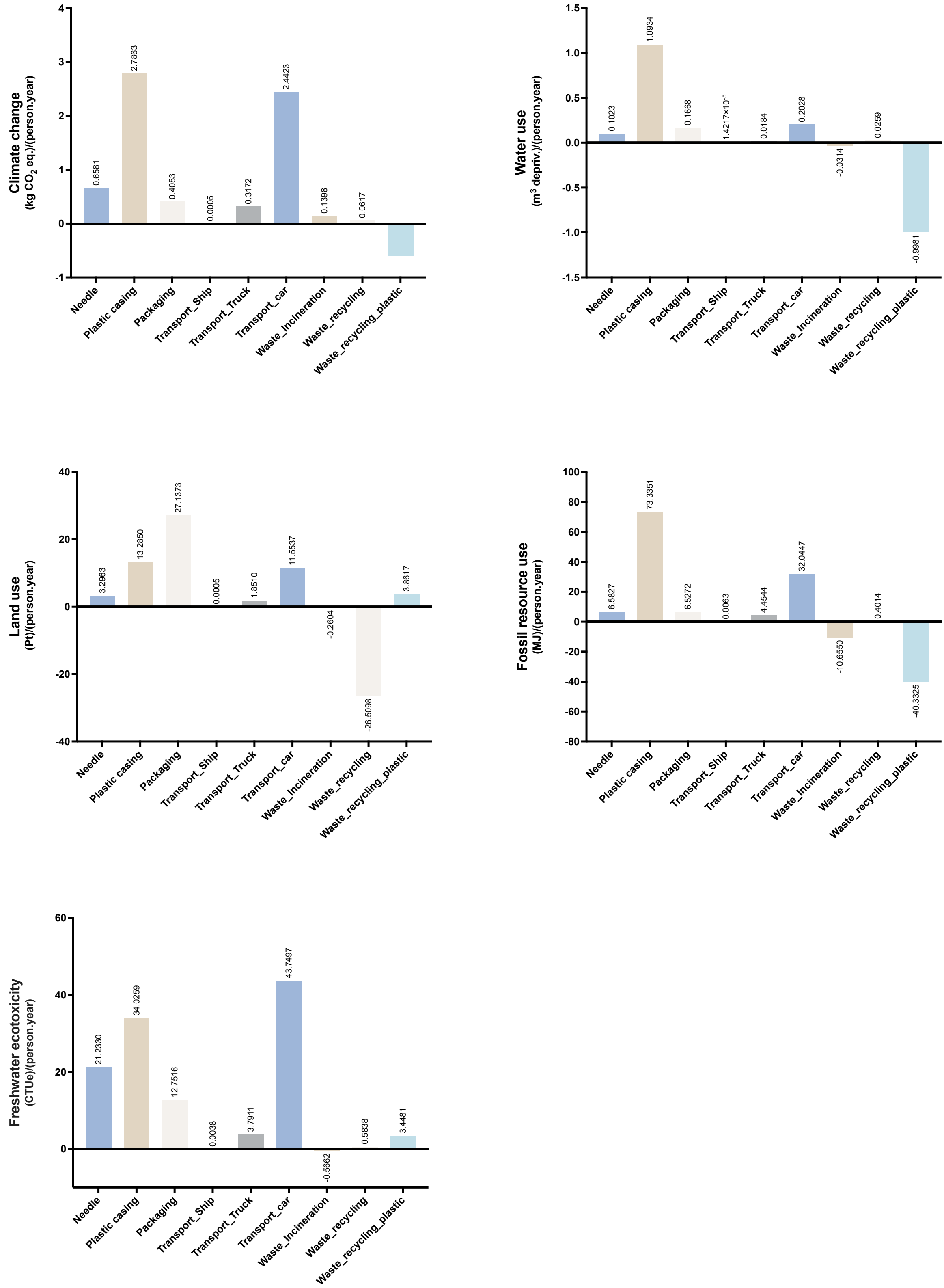


Figure B-IV: The five investigated impact categories of the life cycle of the lancets for the insulin scenario (or in combination with metformin).

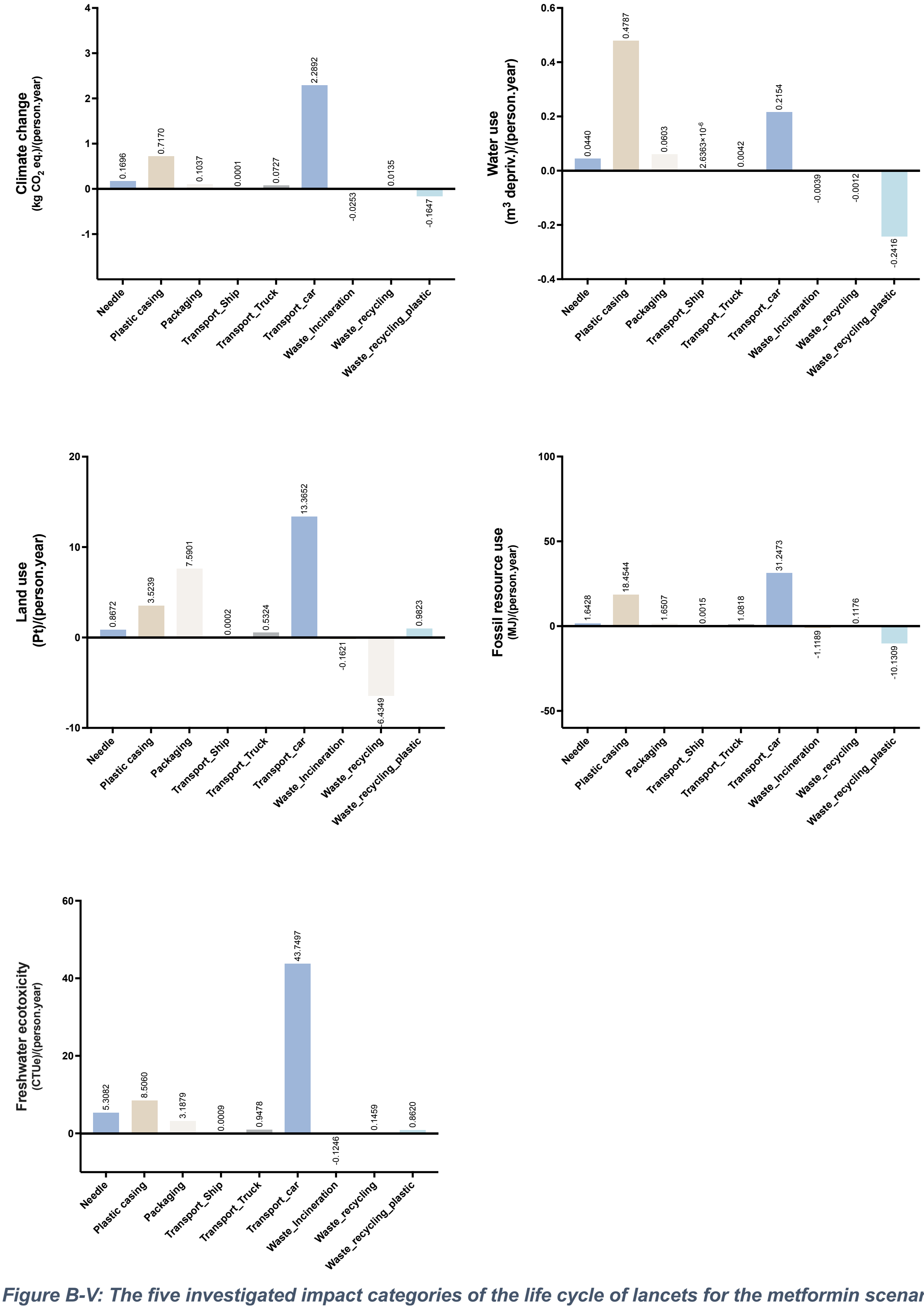


Figure B-V: The five investigated impact categories of the life cycle of lancets for the metformin scenario.

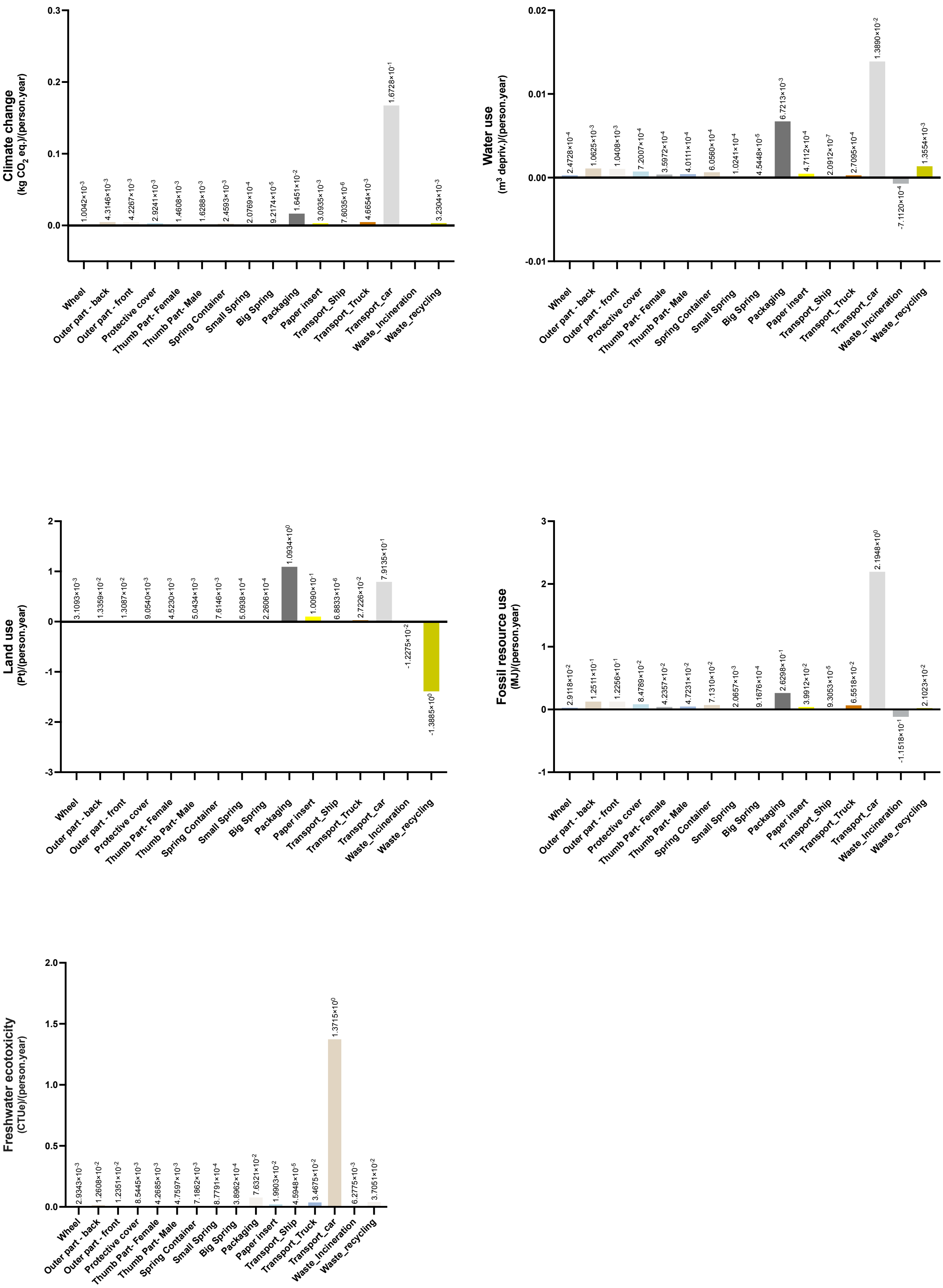


Figure B-VI: The five investigated impact categories of the life cycle of the lancing device.

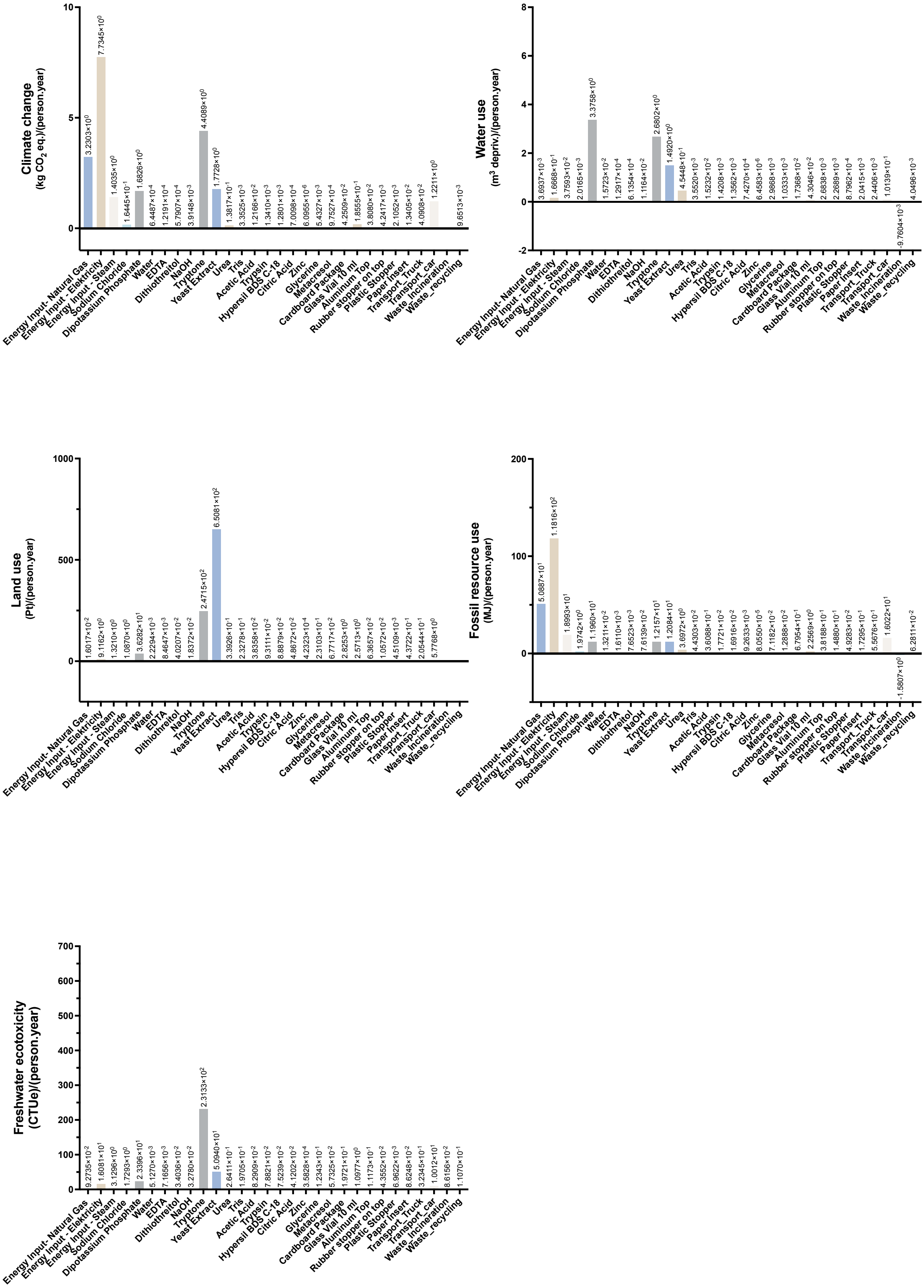


Figure B-VII: The five investigated impact categories of the life cycle of insulin supply.

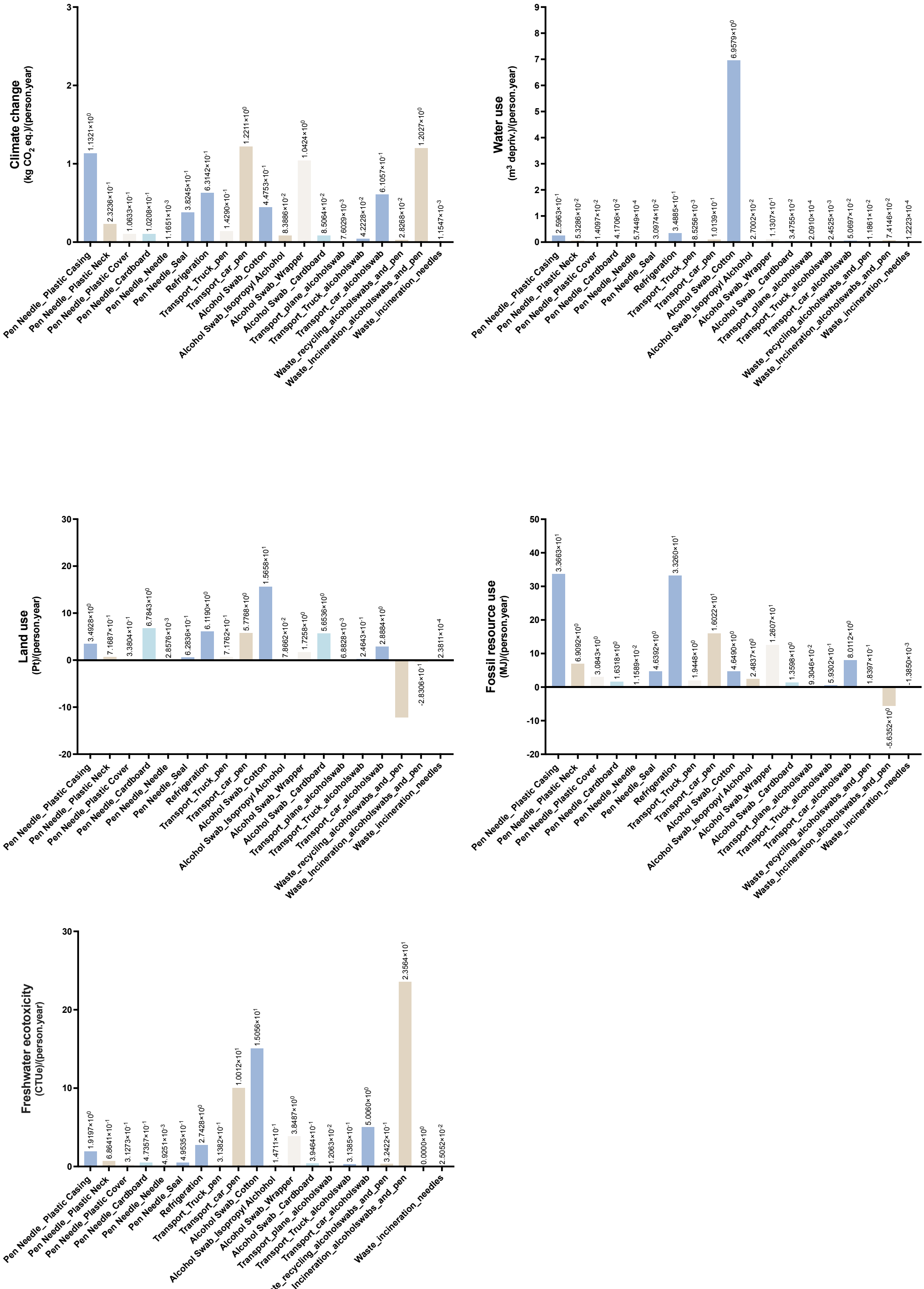


Figure B-VIII: The five investigated impact categories of the life cycle of insulin use.

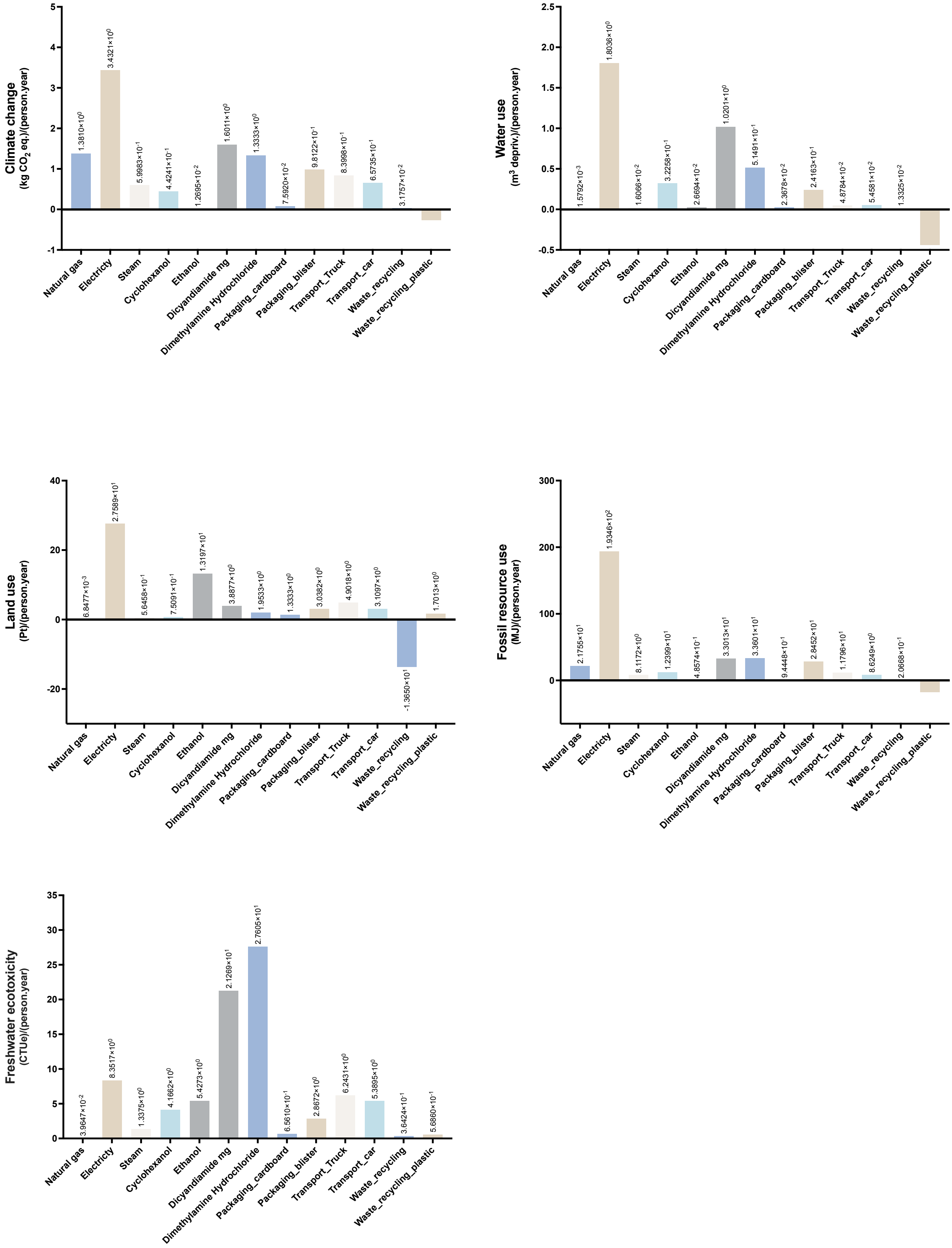
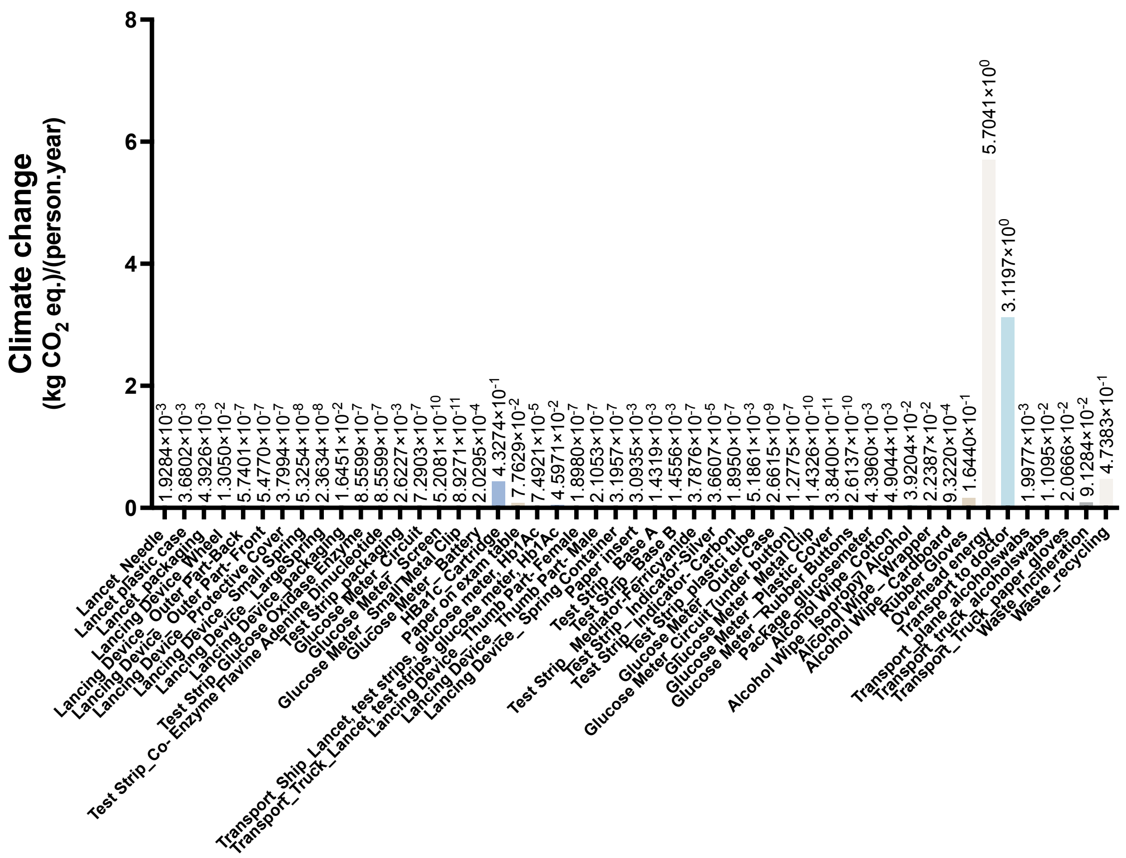
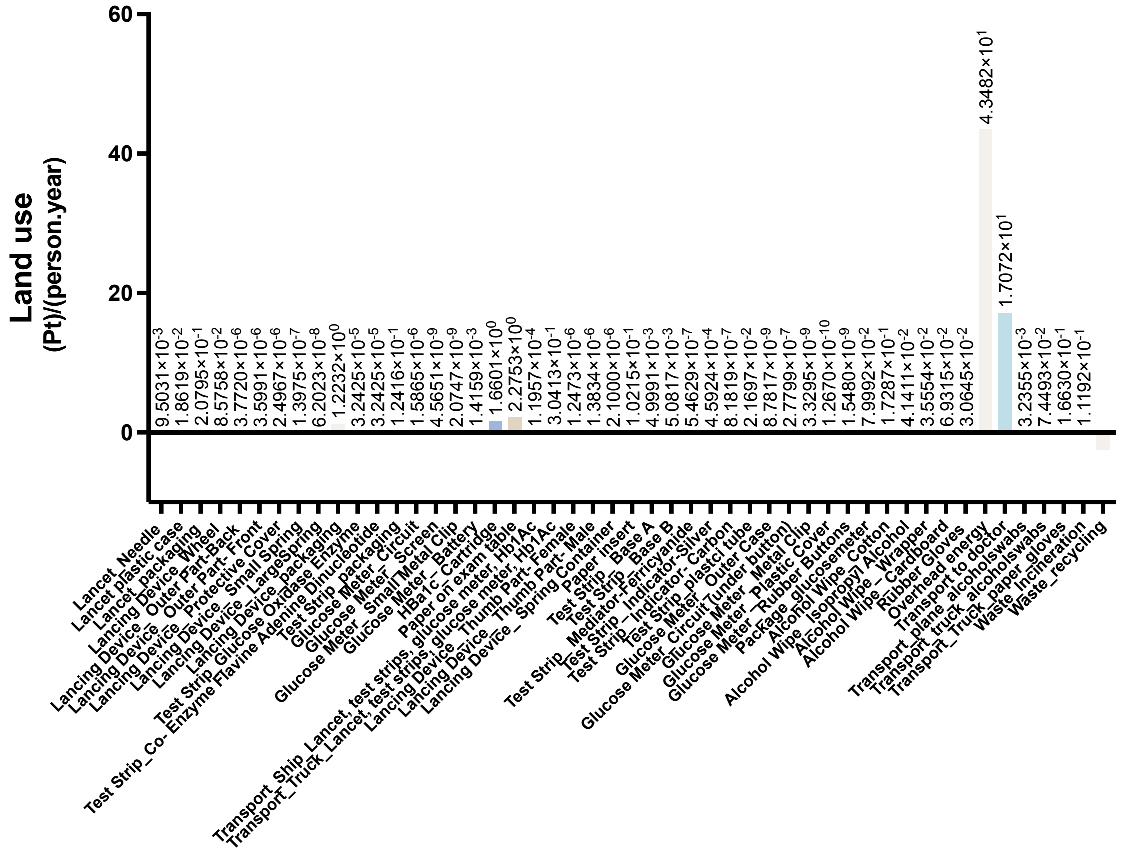
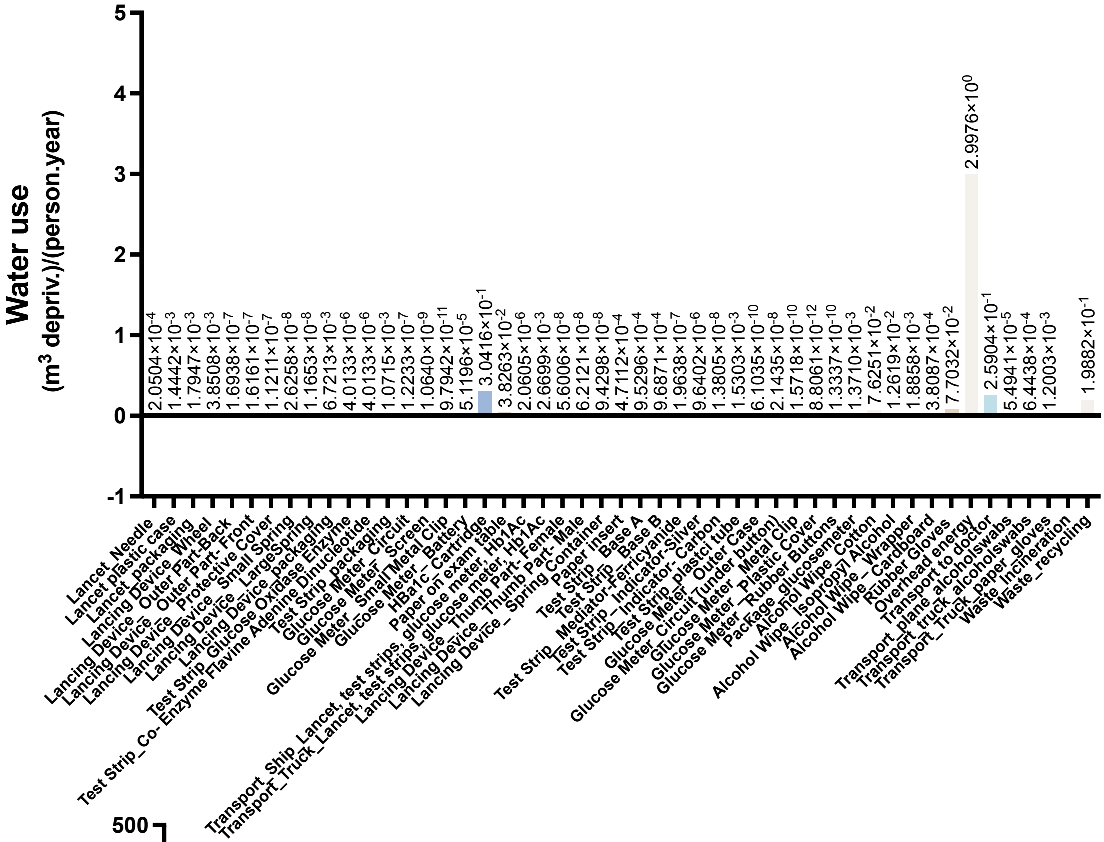
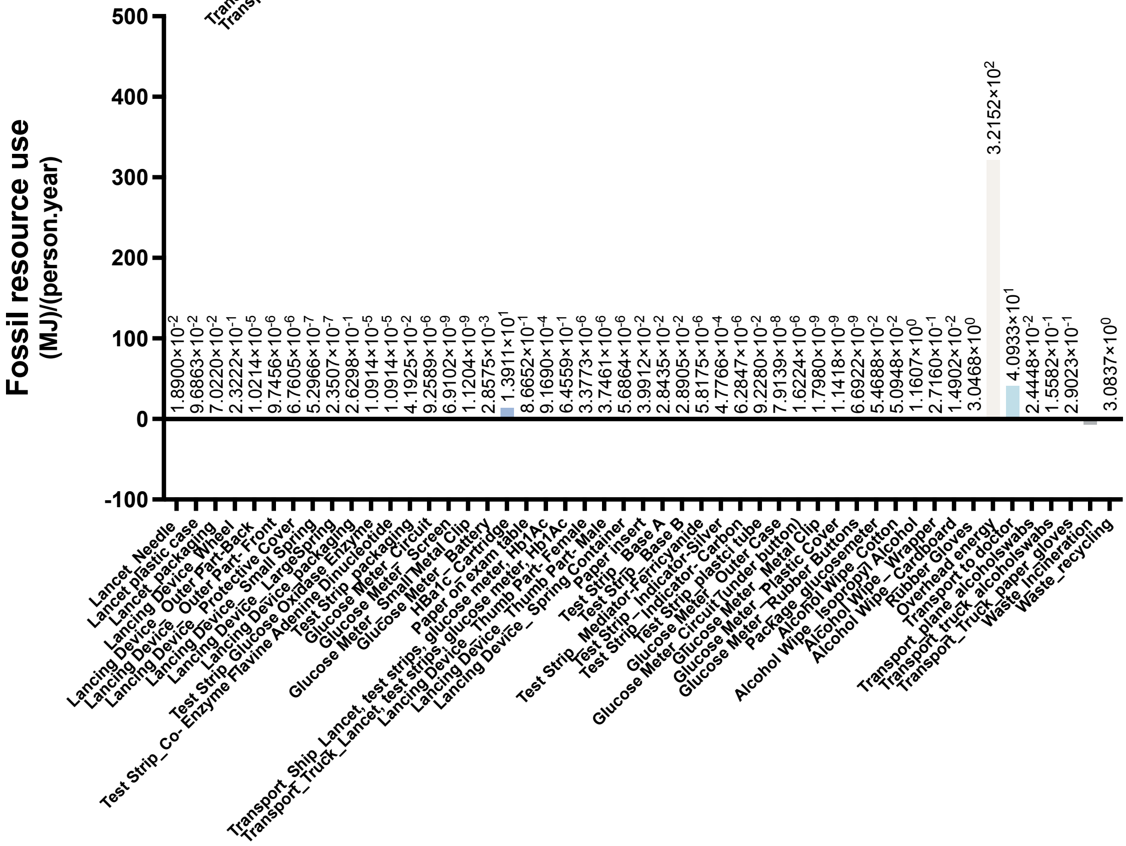


Figure B-IX: The five investigated impact categories of the life cycle of metformin.


Climate change
(kg CO2 eq.)/(person.year)
8
6
4
2
0


Land use
(Pt)/(person.year)
60
40
20
0


Water use
(m3 depriv.)/(person.year)


Fossil resource use
(MJ)/(person.year)

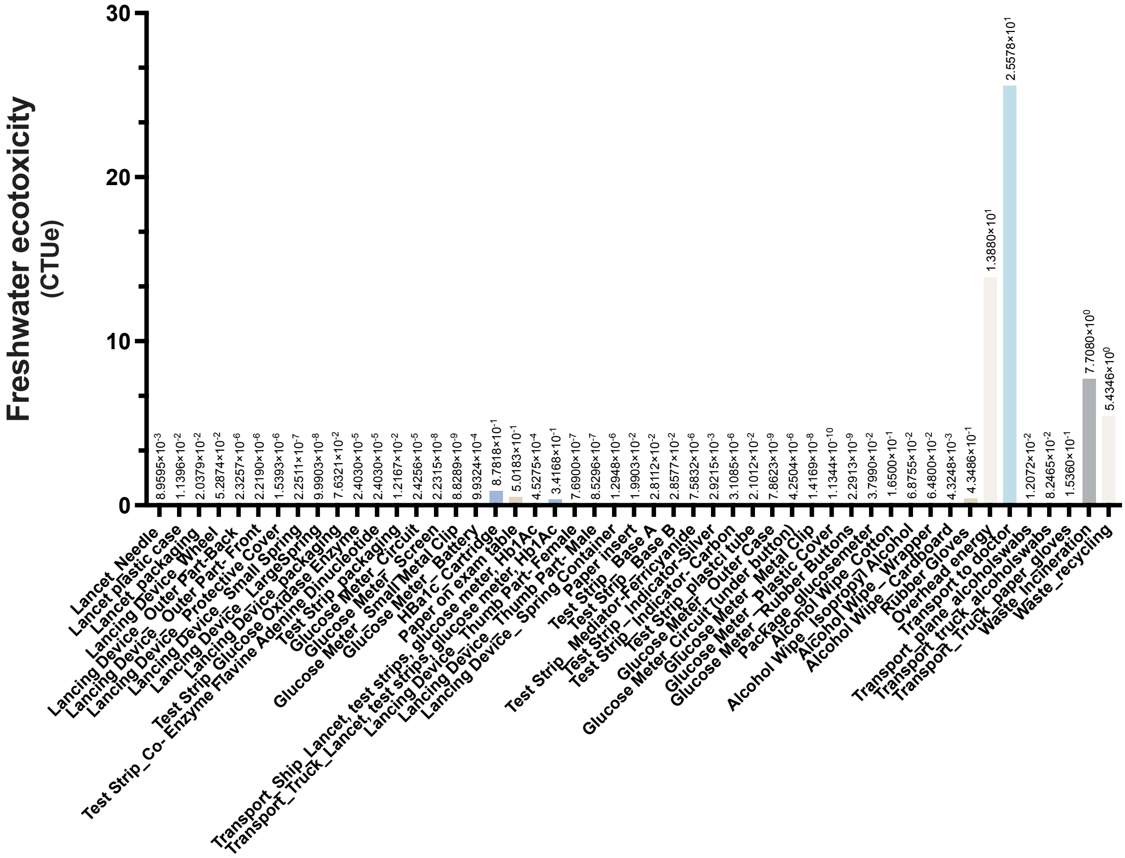
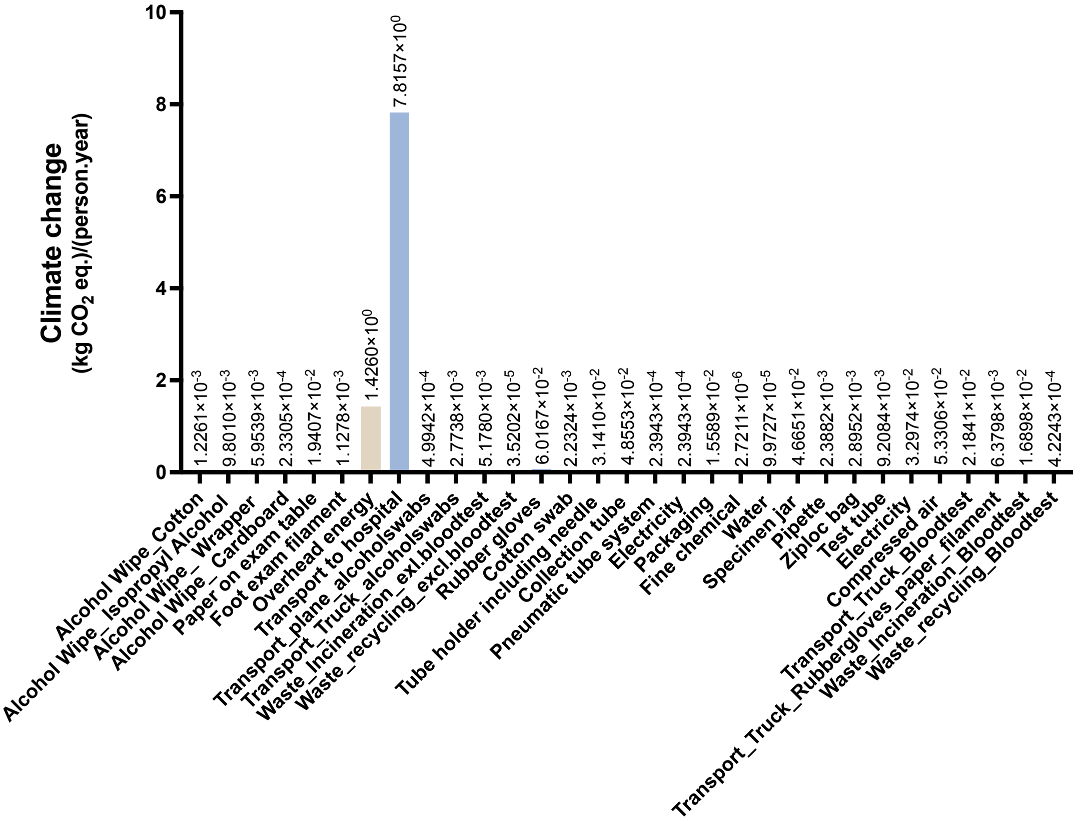
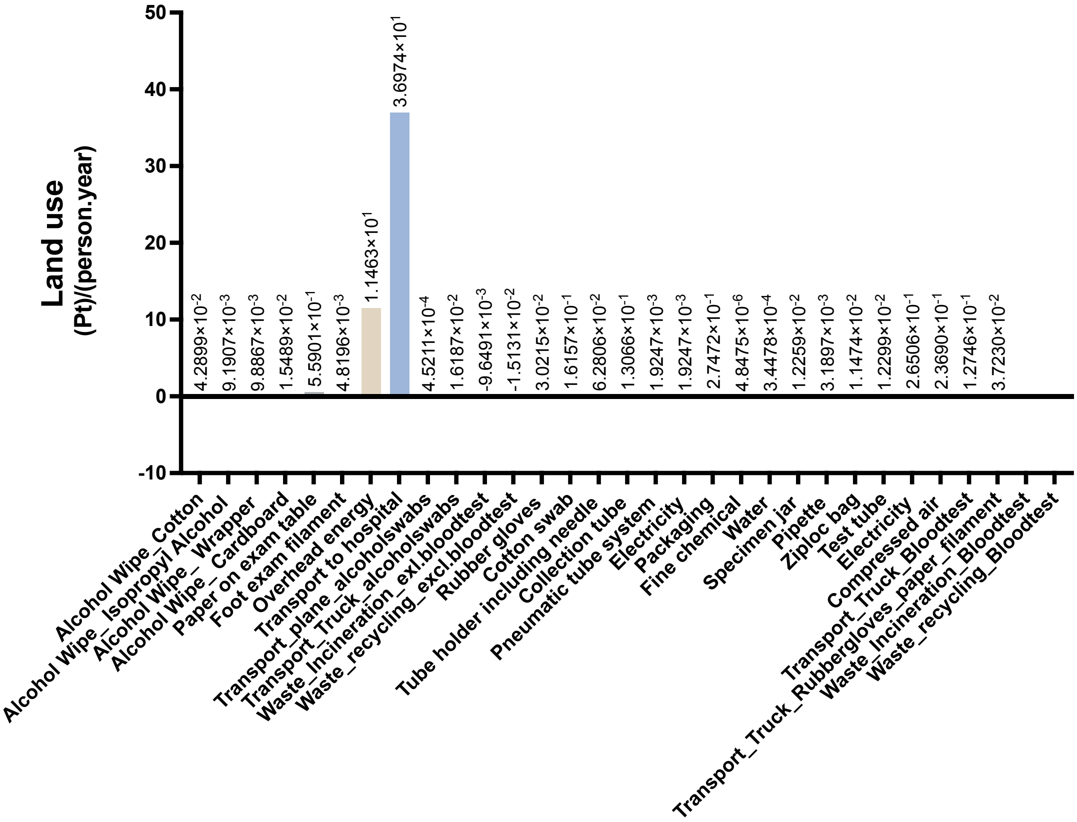


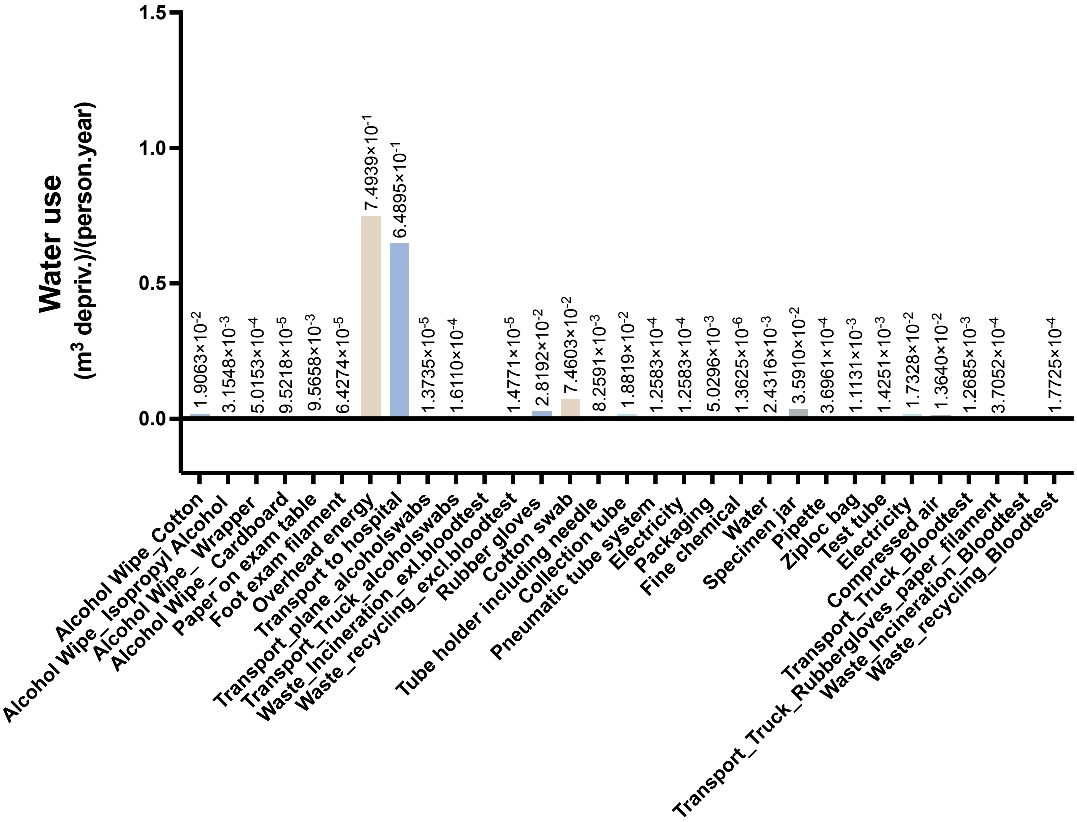
Figure B-X: The five investigated impact categories of the life cycle for the general practitioner (GP) visit.

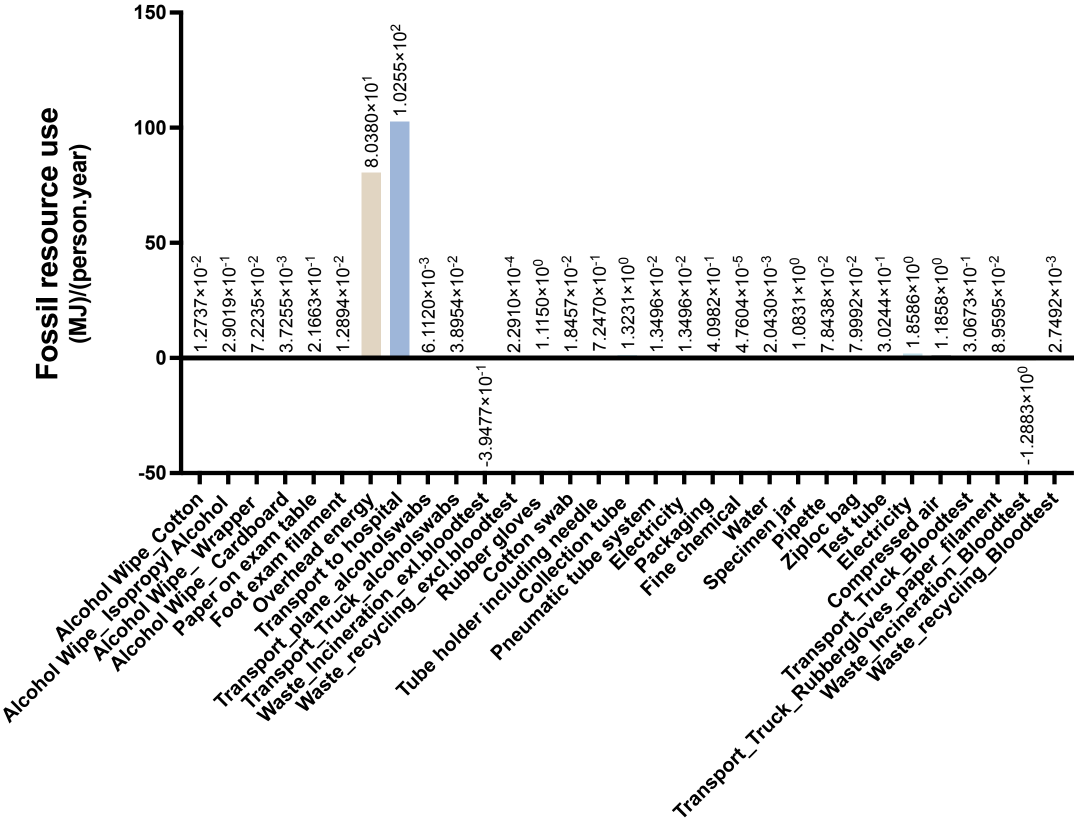


Climate change
(kg CO_2 eq.)/(person.year)
0
2
4
6
8
10
1.2261×10⁻³
9.8010×10⁻³
5.9539×10⁻³
2.3305×10⁻⁴
1.9407×10⁻²
1.1278×10⁻³
1.4260×10⁰
7.8157×10⁰
4.9942×10⁻⁴
2.7738×10⁻³
5.1780×10⁻³
3.5202×10⁻⁵
6.0167×10⁻²
2.2324×10⁻³
3.1410×10⁻²
4.8553×10⁻²
2.3943×10⁻⁴
2.3943×10⁻⁴
1.5589×10⁻²
2.7211×10⁻⁶
9.9727×10⁻⁵
4.6651×10⁻²
2.3882×10⁻³
2.8952×10⁻³
9.2084×10⁻³
3.2974×10⁻²
5.3306×10⁻²
2.1841×10⁻²
6.3798×10⁻³
1.6898×10⁻²
4.2243×10⁻⁴
Alcohol Wipe_Cotton
Alcohol Wipe_Isopropyl Alcohol
Alcohol Wipe_ Wrapper
Alcohol Wipe_ Cardboard
Paper on exam table
Foot exam filament
Overhead energy
Transport to hospital
Transport_plane_alcoholswabs
Transport_Truck_alcoholswabs
Waste_Incineration_exl.bloodtest
Waste_recycling_excl.bloodtest
Rubber gloves
Cotton swab
Tube holder including needle
Collection tube
Pneumatic tube system
Electricity
Packaging
Fine chemical
Water
Specimen jar
Pipette
Ziploc bag
Test tube
Electricity
Compressed air
Transport_Truck_Bloodtest
Transport_Truck_Rubbergloves_paper_filament
Waste_Incineration_Bloodtest
Waste_recycling_Bloodtest



Land use
(Pt)/(person.year)
-10
0
10
20
30
40
50
4.2899×10⁻²
9.1907×10⁻³
9.8867×10⁻³
1.5489×10⁻²
5.5901×10⁻¹
4.8196×10⁻³
1.1463×10¹
3.6974×10¹
4.5211×10⁻⁴
1.6187×10⁻²
-9.6491×10⁻³
-1.5131×10⁻²
3.0215×10⁻²
1.6157×10⁻¹
6.2806×10⁻²
1.3066×10⁻¹
1.9247×10⁻³
1.9247×10⁻³
2.7472×10⁻¹
4.8475×10⁻⁶
3.4478×10⁻⁴
1.2259×10⁻²
3.1897×10⁻³
1.1474×10⁻²
1.2299×10⁻²
2.6506×10⁻¹
2.3690×10⁻¹
1.2746×10⁻¹
3.7230×10⁻²
Alcohol Wipe_Cotton
Alcohol Wipe_Isopropyl Alcohol
Alcohol Wipe_ Wrapper
Alcohol Wipe_ Cardboard
Paper on exam table
Foot exam filament
Overhead energy
Transport to hospital
Transport_plane_alcoholswabs
Transport_Truck_alcoholswabs
Waste_Incineration_exl.bloodtest
Waste_recycling_excl.bloodtest
Rubber gloves
Cotton swab
Tube holder including needle
Collection tube
Pneumatic tube system
Electricity
Packaging
Fine chemical
Water
Specimen jar
Pipette
Ziploc bag
Test tube
Electricity
Compressed air
Transport_Truck_Bloodtest
Transport_Truck_Rubbergloves_paper_filament
Waste_Incineration_Bloodtest
Waste_recycling_Bloodtest


Water use
(m^3 depriv.)/(person.year)
1.5
1.0
0.5
0.0
1.9063×10^{-2}
3.1548×10^{-3}
5.0153×10^{-4}
9.5218×10^{-5}
9.5658×10^{-3}
6.4274×10^{-5}
7.4939×10^{-1}
6.4895×10^{-1}
1.3735×10^{-5}
1.6110×10^{-4}
1.4771×10^{-5}
2.8192×10^{-2}
7.4603×10^{-2}
8.2591×10^{-3}
1.8819×10^{-2}
1.2583×10^{-4}
1.2583×10^{-4}
5.0296×10^{-3}
1.3625×10^{-6}
2.4316×10^{-3}
3.5910×10^{-2}
3.6961×10^{-4}
1.1131×10^{-3}
1.4251×10^{-3}
1.7328×10^{-2}
1.3640×10^{-2}
1.2685×10^{-3}
3.7052×10^{-4}
1.7725×10^{-4}
Alcohol Wipe_Cotton
Alcohol Wipe_Isopropyl Alcohol
Alcohol Wipe_ Wrapper
Alcohol Wipe_ Cardboard
Paper on exam table
Foot exam filament
Overhead energy
Transport to hospital
Transport_plane_alcoholswabs
Transport_Truck_alcoholswabs
Waste_Incineration_exl.bloodtest
Waste_recycling_excl.bloodtest
Rubber gloves
Cotton swab
Tube holder including needle
Collection tube
Pneumatic tube system
Electricity
Packaging
Fine chemical
Water
Specimen jar
Pipette
Ziploc bag
Test tube
Electricity
Compressed air
Transport_Truck_Bloodtest
Transport_Truck_Rubbergloves_paper_filament
Waste_Incineration_Bloodtest
Waste_recycling_Bloodtest


Fossil resource use
(MJ)/(person.year)
150
100
50
0
-50
1.2737×10^{-2}
2.9019×10^{-1}
7.2235×10^{-2}
3.7255×10^{-3}
2.1663×10^{-1}
1.2894×10^{-2}
8.0380×10^{1}
1.0255×10^{2}
6.1120×10^{-3}
3.8954×10^{-2}
-3.9477×10^{-1}
2.2910×10^{-4}
1.1150×10^{0}
1.8457×10^{-2}
7.2470×10^{-1}
1.3231×10^{0}
1.3496×10^{-2}
1.3496×10^{-2}
4.0982×10^{-1}
4.7604×10^{-5}
2.0430×10^{-3}
1.0831×10^{0}
7.8438×10^{-2}
7.9992×10^{-2}
3.0244×10^{-1}
1.8586×10^{0}
1.1858×10^{0}
3.0673×10^{-1}
8.9595×10^{-2}
-1.2883×10^{0}
2.7492×10^{-3}
Alcohol Wipe_Cotton
Alcohol Wipe_Isopropyl Alcohol
Alcohol Wipe_ Wrapper
Alcohol Wipe_ Cardboard
Paper on exam table
Foot exam filament
Overhead energy
Transport to hospital
Transport_plane_alcoholswabs
Transport_Truck_alcoholswabs
Waste_Incineration_exl.bloodtest
Waste_recycling_excl.bloodtest
Rubber gloves
Cotton swab
Tube holder including needle
Collection tube
Pneumatic tube system
Electricity
Packaging
Fine chemical
Water
Specimen jar
Pipette
Ziploc bag
Test tube
Electricity
Compressed air
Transport_Truck_Bloodtest
Transport_Truck_Rubbergloves_paper_filament
Waste_Incineration_Bloodtest
Waste_recycling_Bloodtest

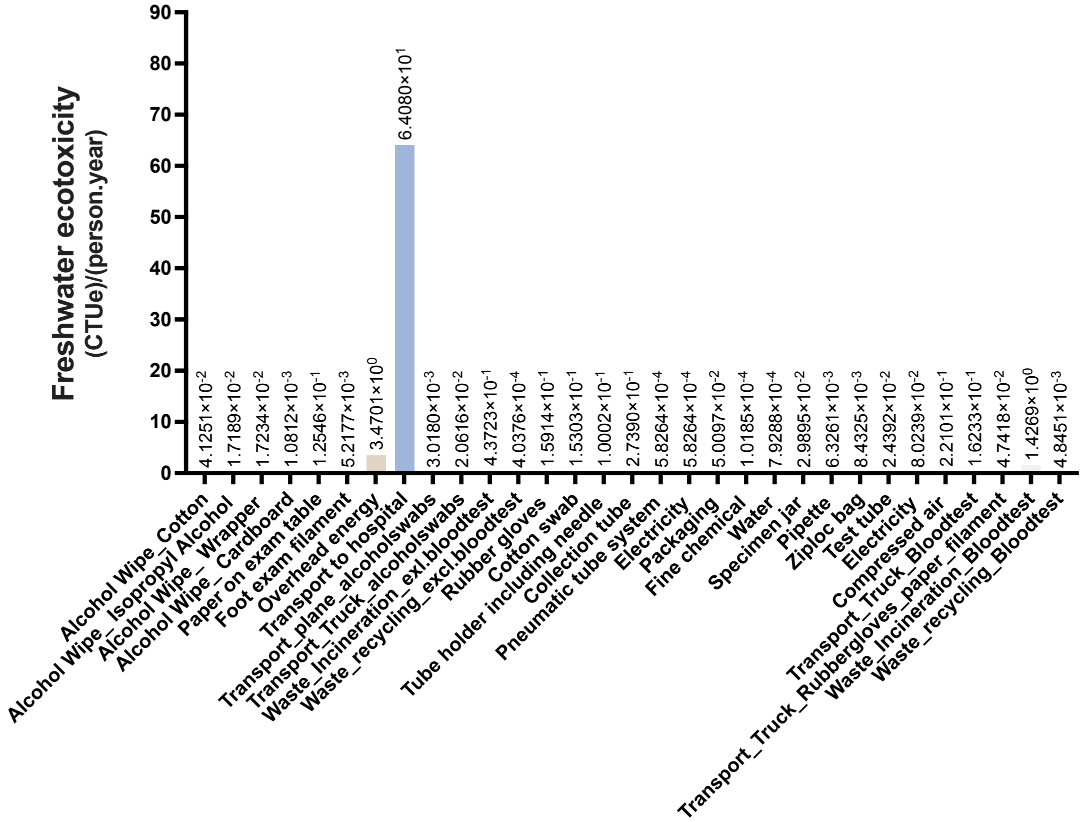


Figure B-XI: The five investigated impact categories of the life cycle for ambulatory care.

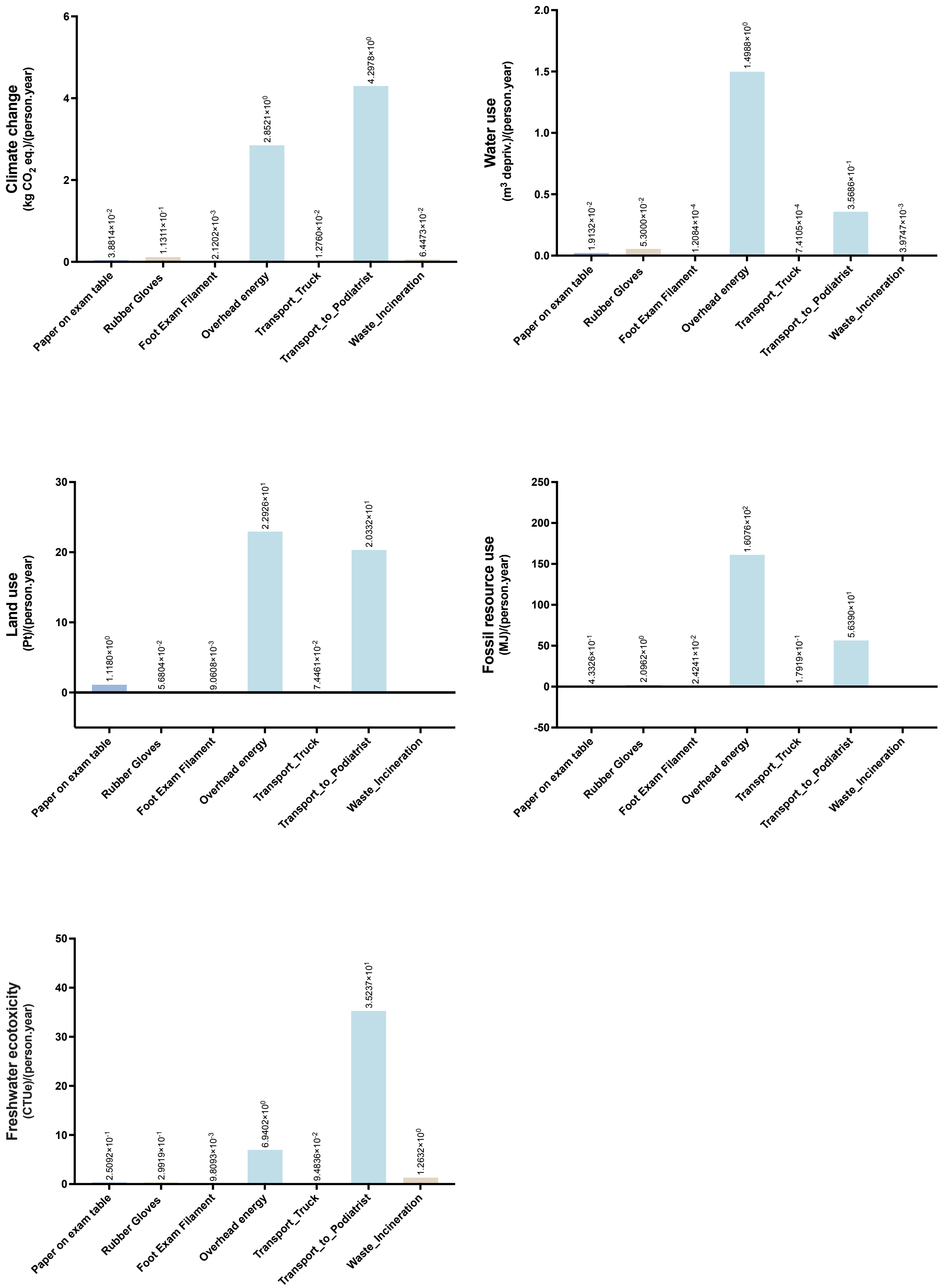


Figure B- XII: The five investigated impact categories of the life cycle of the podiatrist visit.

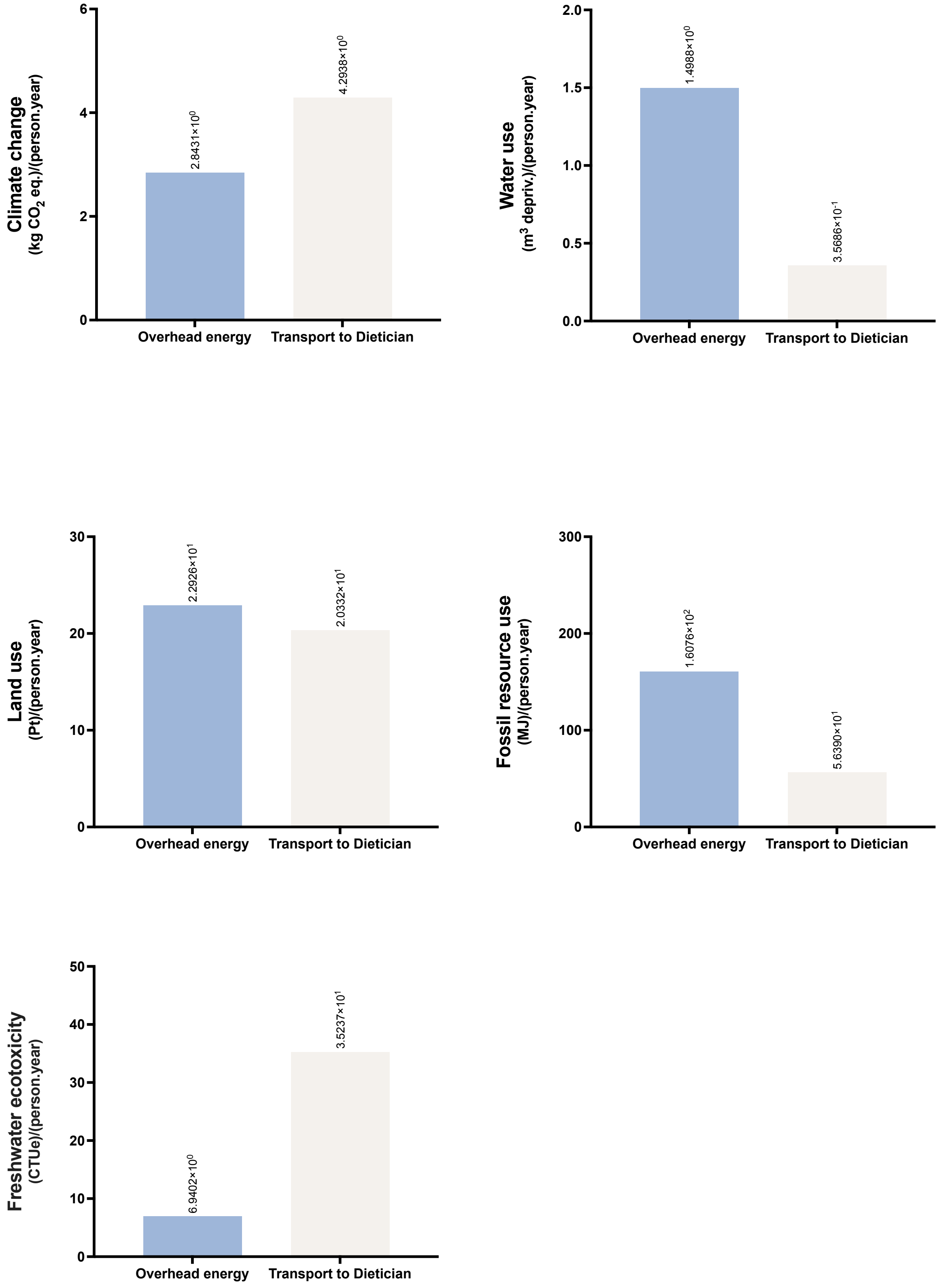


Figure B-XIII: The five investigated impact categories of the life cycle of a visit to the dietician.