Thesis

"Investigating the suitability of simplified, partial LCA results to support decisions to minimise Nexus impacts from restaurant meal consumption in small Dutch cities"

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Author

Ralf Clauβner

Abstract

Environmental impacts related to the global food system are increasingly addressed by academia, institutions, policy-makers and businesses. Fundamentally, decisions about food consumption rest with the customer, and although they are the largest stakeholder group in the food system, they are not adequately equipped to consider the environmental impact of their choices at the time of purchase. The Water-Energy-Food Nexus is a useful perspective to analyse and communicate emissions along the production system, supply chain and consumption context of food. Through the lens of the Nexus, this study investigates the LCA methodology as a mechanism to provide local consumers with useful information about permanent decrease of upstream water and energy availability and associated impacts of restaurant meals. A simplified 'farm-to-fork' LCA assessment was carried out for 12 popular meals that were frequently offered in the Dutch city of Leiden and could be grouped into the four categories red meat-based, poultry-based, fish-based and vegetarian. The ReCiPe and Cumulative Energy Demand impact assessments were applied to identify poultry-based meals with the highest water depletion potential and cumulative energy demand. This surprising result was found to be driven by the large proportion of starch ingredients in the recipes and the absence of significant amounts of starch ingredients in the Red Meat-based meals. The findings revealed a directly proportional relationship between refrigerated storage duration and both assessed impact categories. Normalization of meals per weight significantly reduced the range of impact scores across meals and the normalization of impact categories highlighted the disproportionately large effect of 'freshwater eutrophication' cause by beef cultivation.

The results of the study provide high-level insight for policy-makers, businesses and consumers. The comprehensive metrics in this study are useful for communicating complex environmental impacts with consumers and supporting their decision-making process in favour of less environmentally impactful option. For businesses, a challenge arises from the disproportionately high impacts associated to inexpensive ingredients such as potatoes. Policy-makers are encouraged to further regulate maximum shelf-life durations and thereby curb energy demand for cold storage.

In the context of the Water-Food-Energy Nexus, it was found that the study results support integrated measures that allow consumers to make more informed decisions, businesses to shift to low-impact ingredients without an economic disadvantage and policy-makers to stimulate more rigorous and feasible management of impacts along the food system.

Contents

1 Introduction

In this section, the level of involvement of the major stakeholder groups in the global food system position food as a central driver of cross-industry environmental impacts. Stakeholder roles and their engagement indicate opportunities and gaps around food sustainability.

1.1 Sustainable food and the Nexus

According to UN Water, there are high dependencies between food, water and energy. Food-related activities account for 70% of global water abstraction and 30% of global energy demand (United Nations, n.d.). The data hints at the relevance and connectedness of the dimension of food within the Water-Energy-Food nexus (Nexus). It is widely accepted that the Nexus was formally established by Hoff in at the 'Bonn 2011 Conference: The Water, Energy and Food Security Nexus' (Hoff, 2011).

In 2014, the FAO adopted a Nexus approach to food security, sustainable agriculture and an increase in food demand of 60% by 2050 and (FAO, 2014b). The equal focus on the three dimensions of water, energy and food avoids prioritization of individual dimensions such as water through the Integrated Water Resource Management. Similarly, local governments such as the Dutch government advocate the minimisation of environmental impacts in the farming industry by way of increasing efficiencies in water and energy use, thus supporting a Nexus approach (Government of the Netherlands, n.d.). Frequently, high impact sectors such as livestock and dairy production are addressed.

Figure 1.1 highlights the nature and density of interconnections between the Nexus' three dimensions, based on a case-study of Matagorda County, Texas.

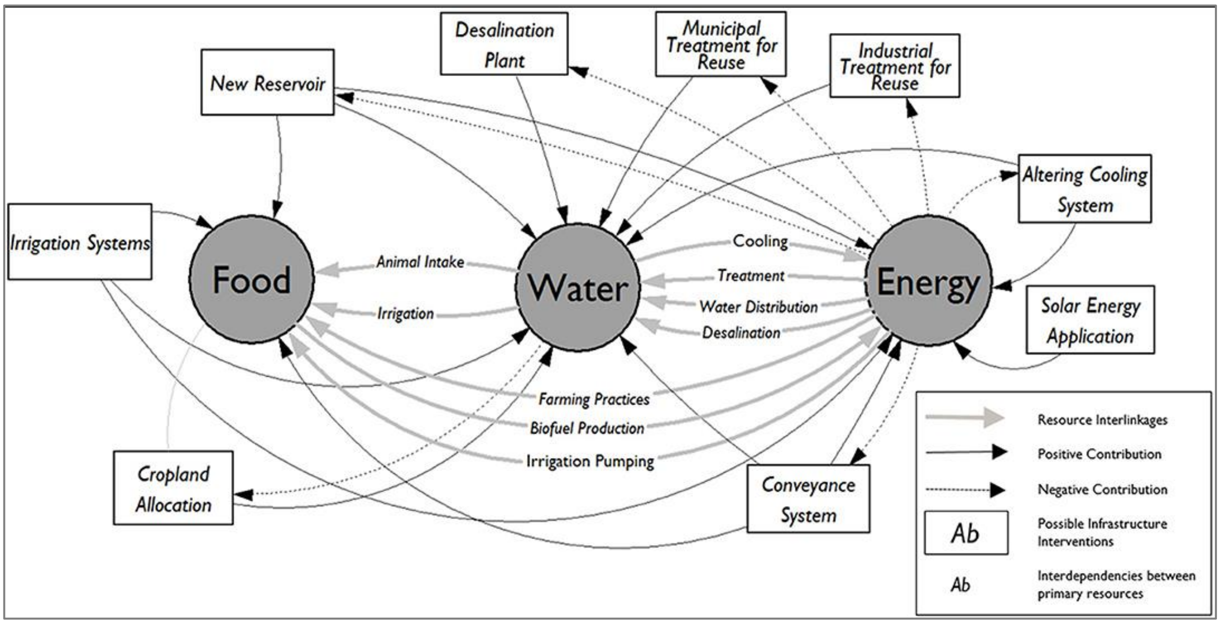

Figure 1.1 - Schematic Overview of the WEF Nexus Model (Kulat, Mohtar, & Olivera, 2019)

Efficiency gains are often based on technology-based optimisation, which may reduce some dependencies but increase others. This relationship was clearly illustrated by research at Wageningen University and Research: Tech-enhanced tomato cultivation increases production yield almost 3-fold while direct water use was reduced by 95%. At the same time, energy use increased more than 20-fold (Campen, 2017). As shown in Figure 1.1, energy production also requires water, which is estimated to be approximately 0.76 litres per MJ in Europe (Gadonneix, Barnés De Castro, & Drouin, 2010). As a result, the savings of direct water are likely offset by the indirect use of water in energy production.

1.2 Alignment of stakeholders in food sustainability policy and research

Policy recommendations and frameworks frequently support an integrated systemic approach to food sustainability issues with an emphasis on consumer empowerment through robust information.

The European Commission recommends the Product Environmental Footprint (PEF) method to assess the environmental performance of products and organisations as an 'essential element in the environmental decision-making of a wide range of actors' (European Commission, 2013). The PEF's methodology is largely identical with life-cycle assessment (LCA) as defined in ISO 14044 (International Organization for Standardization, 2006). More specifically in the context of the food system, the European Commission is co-chairing the Food Sustainable Consumption and Production Round Table, which defines LCA and PEF as the fundamental analysis methods in its ENVIFOOD protocol. It defines three key objectives to achieve more sustainable consumption and production of food, one of which is the 'identification of suitable communication tools to consumers and other stakeholders, looking at all channels and means of communication' (Food SCP Round Table, n.d.). Further, the protocol's lead principle is to support informed choices by means of communicating scientifically reliable, consistent and understandable environmental information along the food chain, including the consumer (Food SCP RT, 2013).

Based on the FAO's statistical data from 2011, balancing inputs and outputs of the global food system shows that inefficiencies differ significantly between regions and food groups (FAO, 2011). Sustainability of food is generally analysed in the context of systems within a certain region (Metabolic, 2018b), with respect to farming practices (European Environment Agency, n.d.) or food groups (Zocca, Gaspar, da Silva, Nunes, & de Andrade, 2018), or a combination thereof (Gladek et al., 2016). Nexus-related activities are largely academic and have a strong link to policy and governance institutions. Research projects apply a variety of methods to analyse local production systems and take regional water and energy policy contexts into account (Endo, Tsurita, Burnett, & Orencio, 2017). Most Nexus research is focused on water use and stress. Nexus studies of all three elements currently fall within the field of biofuels.

Generally, Nexus- and LCA-based scientific methods to assess the environmental impact of foods are at the forefront of sustainability agendas.

1.3 Activation of decision-makers

Currently, most efforts to develop sustainable food systems in practice are directed towards agri-businesses and their capacity to implement technological innovation, managerial change and production efficiencies (Garnett, 2013, Government of the Netherlands, n.d.). This approach may lead to greater overall sustainability gains, but local initiatives can also result in significant benefits (Smith, 2008). In either context, the responsibility of transitioning to a sustainable food system needs to become more distributed across production, governance and consumption stakeholders (Garnett, 2013).

Within the Dutch food system (Figure 1.2), the low concentration of powers among the consumer means that other stakeholders achieve their own goals more easily, which may not primarily align with an environmental sustainability agenda (PBL Netherlands Environmental Assessment Agency, n.d.).

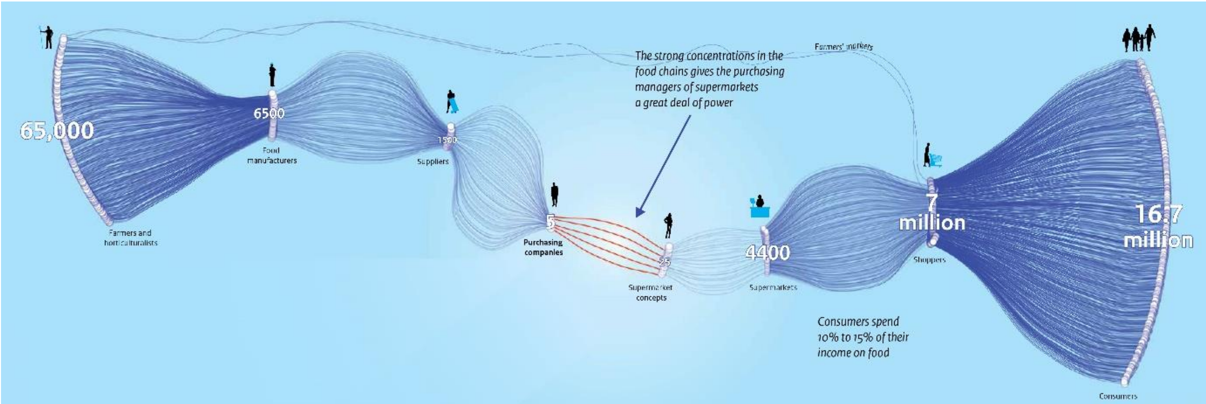

Figure 1.2 - Concentrations in the Dutch food chain

Food consumers in western cultures increasingly opt for ready-to-eat meals, spend less time preparing food and more often consume food outside of the home (Geurts, van Bakel, van Rossum, de Boer, & Ocké, 2017). As a result, identifying and communicating the environmental impacts of such meals is receiving more attention from the food retail and hospitality industry as well as researchers (Kneafsey et al., 2015). Sustainable food recommendations mostly target meat-free and low-dairy diets (Brink, Postma-Smeets, Stafleu, & Wolvers, 2017; Garnett, 2013; Vanham, Mak, & Gawlik, 2016).

Stichting Duurzame Horeca Leiden En Omstreken has the simple but ambitious goal of making restaurants and bars more sustainable. The organisation's website lists a number of questions a patron can ask which may lead to more awareness or even action towards a more sustainable operation of the business and its offerings (Stichting Duurzame Horeca Leiden en omstreken, n.d.). However, regardless of what choice is made, with the exclusion of ordering a half-portion, neither consumer nor service provider can reasonably quantify the impact of their decision.

1.4 Problem statement and research gap

Any economic system follows the dynamics of supply and demand. As such, the food system is subject to consumer's demand of products on a local as well as on a global level. An increasing awareness of food sustainability issues has produced scientific research and their findings have influenced agendas for effective policy across global, regional and national levels.

Consumers are the largest stakeholder group in any food system and they have the potential to influence the global food system from a local level. At the same time, consumption of food is shifting to a semi-industrial environment that is more controllable than home-cooking. However, while various actors along the supply chain increasingly improve their efficiencies and reduce environmental burdens, it could be argued that consumers are currently without useful, simple and comprehensively applicable information to fundamentally drive a transition towards a more sustainable food system.

Research has sufficiently identified risks and opportunities associated with individual food items, generic meals or national diets. However, results are often incomparable because of specific modelling choices and the use of various impact indicators that are expressed in units that are not meaningful to the general population.

Considering the significance of consumer choices within the Dutch food system and a record growth of restaurant sales in 2017 (CBS, 2018), it seems relevant to generate comprehensive information for consumers at the moment of selecting options from a restaurant menu. Further, food LCAs must address location-specific challenges to support effective decision-making. All stakeholder groups including policy-makers and producers should be enabled to contribute to reducing the environmental impact of locally consumed foods. As the food system is linked to local and global factors in any given environment, an integrated and useful approach is proposed to analyse and communicate the environmental impacts of foods.

In summary, the identified research gaps are:

- Nexus-relevant indicators that are useful to the consumer
- Research tailored to consumption patterns in a specific location, which will be the Dutch city of Leiden for the purpose of this study
- Comprehensive and applicable for multiple stakeholder groups

1.5 Research questions

In response to these gaps, this study attempts to quantify Nexus-relevant environmental impacts of meals that are served in sit-down restaurants in Leiden. The results of the study must be communicable to a non-scientific audience but remain scientifically robust. In addition to the general public, the results should enable discussions among policy-makers, business owners, suppliers and producers, and stimulate actions in support of a more sustainable food supply chain.

Subsequently, the main research question for this study will be as follows:

Can the results of simplified, partial LCAs of restaurant meals in a medium-sized city in the Netherlands support decisions to reduce the environmental impact of the food system?

The following series of sub-questions will support a structured approach:

1) What are the comparative upstream energy and water demands of these dishes at the point of consumption?
2) How reliable are the results of a simplified LCA method for these indicators?
3) How can the results support decision-making of other stakeholders in the food system in the context of Leiden and other Dutch cities?

1.6 Structure of this study

Chapter 2 gives an overview of current research approaches, frameworks and positions within the research community. Recent publications with a focus on food LCAs in a Nexus context and concerning consumer information are reviewed. A research gap is identified which leads to the formulation of the main research question and sub-questions. Finally, central challenges are highlighted at the end of this chapter.

Chapter 3 defines the research approach and applied methods of data collection and analysis. Further, methodological challenges and reliability, validity and generalizability issues are raised.

In chapter 4, the results are presented alongside all assumptions and additional inputs. Discrepancies between internal and external results and dataset are analysed as well as the sensitivity and remaining uncertainties within the model.

Chapter 5 contains the discussion of overall challenges within the methodology and the applicability, relevance and usefulness of the results across the dimensions of stakeholders, locations and industries. This will provide an interdisciplinary Industrial Ecology perspective.

Chapter 6 reviews the project, answers the main research question and offers recommendations for further research.

2 Literature review and research framework

The literature review is mostly based on repositories of scientific publications such as Scopus (Scopus, 2019), ScienceDirect (ScienceDirect, 2019) as well as background resources of various FAO, UN, European Commission and WHO reports. Key search terms included "Water-Energy-Food Nexus", "food sustainability", "food LCA", "food footprint" and others. Where possible, resources with specific links or mentions of The Netherlands were used.

2.1 Consensus of food sustainability issues and potential intervention strategies among policy-makers and the public

For more than a decade, institutions have been acknowledging the environmental impacts of food systems with increasing definition and urgency. Food and drink products were found to be significant contributors to environmental impacts from consumer goods in 2006 (European Commission, 2006). The FAO formalized the link between food production and an increasingly intensive competition for the resources energy, water and land (FAO, 2009), which officially became a theme with Hoff's contribution to the Bonn 2011 Conference: The Water, Energy and Food Security Nexus (Hoff, 2011). At the same time, the UK government recognized that the competition for energy and water demand is becoming a threat to the future of food production and 'conversely, growth in the food system will itself exacerbate these pressures' (Webb et al., 2011). With the Nexus even being considered one of four mega-trends for 2030 (National Intelligence Council, 2012), the interconnectedness of the three core dimensions of Food, Energy and Water and their reciprocal dependencies became a focus of research. The FAO has since included the Nexus in its vision for sustainable food and agriculture (FAO, 2014a). And while the EU's policy agenda also addresses a sustainable food system by way of efficiency gains in resource use (European Environment Agency, 2017), the WHO has not yet included any sustainability themes in its European Food Action Plan 2015-2020 (WHO - Regional Committee for Europe, 2014).

Efficiency gains in the food system currently focus on wastage, which has been identified and analysed as a major issue of environmental impacts along the supply chain (FAO, 2013). In the EU, an estimated 30% of wastage occurs during the production and processing stages of food products, while consumers have influence over retail, service and household food waste amounting to the remaining 70% (European Environment Agency, 2014; Stenmark, Jensen, Quested, & Moates, 2016). As a starting point, the EEA argues that reducing inefficiencies in one system almost always has the same effect on linked systems and therefore creates a 'win-win scenario' (European Environment Agency, 2014). Effectively, the reducing food waste may have a positive effect on the other two Nexus dimensions of energy and water.

Achieving any such benefits must consider the global complexity of the food system. However, in its assessment proposal, the FAO advocates focussing on only the most relevant relationships within a country-specific context (FAO, 2014c). This may be realised by addressing high impact sectors in the farming industry such as livestock and dairy production, as the Dutch government has put forward (Government of the Netherlands, n.d.).

As another significant stakeholder group in the Dutch food system, consumers and their choices can contribute to a reduction of environmental impacts from food consumption. Shifting the current diet of the Dutch population (van Rossum et al., 2016) to a more sustainable alternative could also focus on the livestock sector by way of lowering meat consumption and higher intake of plant-based proteins (Brink et al., 2017). Brit et al discuss healthy and sustainable diets in the EU, where the Union's Common Agriculture Policy (CAP) prioritizes biodiversity, natural and traditional farming landscapes, and water management and climate change challenges in general. The authors refer to the Nuffield intervention ladder to achieve a sustainable diet, of which the first step is provision of information to the people (Brit et al., 2017).

In a broad public consultation in 2013, the European Commission found that all participating groups consistently rated 'transparent and accessible data on the environmental impacts of food' as the most effective measure to achieve 'better technical knowledge on the environmental impacts of food products'. The participating groups were representatives from production and agriculture, manufacturing, wholesale and retail, consumer organisations, governmental, welfare and health as well as individuals (European Commission, 2016). Now mandatory nutritional labelling of foodstuffs was implemented in 1990 with the goal of 'enabling the consumer to make (…) [a] choice' and 'assist action in the area of nutrition education for the public' (Commission of European Communities, 2008; European Communities, 2000). Yet, there is a 'gap between established monitoring, data and indicators and the knowledge required to support transitions' and a clear need for concrete knowledge (European Environment Agency, 2017). In support of closing this gap, the allows information to be added to food labels in the future '…if and where necessary, in accordance with the principles of […] sustainability' (European Communities, 2000).

An example of such policy-driven food labelling has been implemented in the US. As a result of the Affordable Care Act, food retailers with more than 20 outlets have to provide information about calorific content of all fresh and packaged foods on offer (US FDA, n.d.). However, calorific information may be relevant for health-conscious decision-making, but has less bearing on environmental choices when dining out (Filimonau, Lemmer, Marshall, & Bejjani, 2017a). Other than including specific data on labels, the display of certification can also support sustainability initiatives in public food environments (University of the West of England, n.d.). However, the Dutch government argues that the current landscape of labels, certificates and logos is confusing and in need of improvement (Ministry of Agriculture Nature and Food Quality (LNV), 2009). More clarity may be achieved by use of more comprehensive metrics that still capture the complex, pluralistic nature of environmental impacts of the food system.

2.2 Overview of research methods regarding food sustainability

Various methods are available to assess the environmental impact of food products. Most methods are bound by restrictions related to impact categories (i.e. single impact category such as water or greenhouse gases) or proxies (i.e. economic value). At the same time, few methods inherently support comparisons between alternatives (Lillywhite, 2010).

Life-cycle assessment has been identified as the least limited method to assess all relevant environmental loads (Mannan, Al-Ansari, Mackey, & Al-Ghamdi, 2018), but there is also a consensus that a limited selection of indicators could make food LCA results more comprehensive for a non-scientific audience (van Dooren & Brink, 2017). Cumulative Energy Demand (CED), land use and greenhouse gas emissions are considered useful screening indicators of environmental impacts, especially when waste treatment is excluded from an LCA (Hallström, Carlsson-Kanyama, & Börjesson, 2015; Huijbregts et al., 2006; Jungbluth, 2011). Methodologically, food LCAs require accurate, local, non-aggregated, quantitative, primary data of specific meals, using mass- or area-based functional units and distinguish by extensive, intensive and organic production methods (Jacobs & Klosse, 2016; Sala et al., 2017; Staatsen et al., 2017).

Several tools and service providers support food LCAs. Agri-Footprint compiles Dutch food industry data for cradle-to-gate LCAs and satisfies EU product environmental footprint and ENVIFOOD recommendations via the ReCiPe midpoint calculation method (Agri-footprint.com, n.d.). Similarly, the ESU World Food LCA Database offers analysis of various individual food items and few meals. Its process inventory is based on ecoinvent3.3 for background data (ESU-services Ltd., n.d.).

Besides proprietary and commercial background databases such as ecoinvent (EI), which currently contains very limited regional food data, Agribalyse (AB) contains an extensive farm-gate life-cycle inventory database of French agricultural products (French Environment & Energy Management Agency, n.d.).

As an alternative, water footprint data is already available for various animal and crop products on a national and global level (Chapagain & Hoekstra, 2004; M. M. Mekonnen & Hoekstra, 2011a, 2011b; M M Mekonnen & Hoekstra, 2010). Based on a water footprint analysis of diets in Nordic cities, a vegetarian diet without animal fats is recommended, which is also applicable to Dutch cities (Vanham, Gawlik, & Bidoglio, 2017; Vanham et al., 2016). However, simplification of environmental impact analysis must be carefully considered, as understanding such indicators and results does not imply a positive response and may even distract from more complex relationships within the food system (Johnson, Hamilton, & Senge, 2009). As such, communicating the environmental impact of food products based on water footprints alone may not be sufficient.

In a food retail environment, positioning of relevant food items in more prominent locations can help to increase the consumption of more sustainable products (Veldhuis, Mensink, & Wolvers, 2017). Sustainability measures in restaurants in particular target operational efficiencies of water and energy use. Further, supply chain management with a focus on local, organic and healthy ingredients can help to reduce environmental impacts overall (Prigge, n.d.; Stichting Duurzame Horeca Leiden en omstreken, n.d.). Both energy and water are useful indicators to illustrate differences between equally nutritious vegetarian and carnivorous diets with a factor of 2.5 and almost 3 respectively (Donati et al., 2016). However, there may be trade-offs between sustainable and nutritious foods (Garnett, 2016).

2.3 Recent food LCA publications

The results from an LCA of a representative European basket of foods show that agricultural production, processing and logistics have the highest impacts. Most impactful food groups are meat and dairy products. Most of the data used for this study is secondary data and represents generic food consumption habits in the EU. Nevertheless, its results correspond with other LCA studies and favour a vegetarian or vegan diet as well as organic and local production over the current food system (Notarnicola, Tassielli, Renzulli, Castellani, & Sala, 2017).

Global Warming Potential (GWP) and land use were selected as representative impact categories for a caloric LCA of urban and peri-urban diets in Lisbon. The results confirmed that changes in diets toward more plant-based products, local sourcing and reduction of waste and losses have significant positive effects on environmental impacts (Benis & Ferrao, 2017).

The concept of *food miles* cannot capture production and transport methods that are location-specific and which may significantly contribute to environmental impacts. This was shown by a split of LCA stages into 'inputs', 'farm (production)', 'distribution', 'consumption' & 'waste disposal'. The results indicate that local off-season production is undesirable compared to imported foods from in-season locations, except when air-freighted (Canals, Muñoz, Hospido, Plassmann, & McLaren, 2008).

A comparison of 13 tomato products found that cultivation and packaging contribute most to environmental impacts (Del Borghi, Gallo, Strazza, & Del Borghi, 2014). The authors recommend lighter packaging materials and more efficient irrigation systems, highlighting the importance of a product's water footprint. Comparing Moroccan and French tomato production systems could not establish a preference of either option because of irreconcilable water and energy trade-offs (Payen, Basset-mens, & Perret, 2014). However, the study highlighted the importance of including freshwater use in the assessment. In contrast, another study on protected tomato production systems in the Netherlands, Hungary and Spain concluded that the reduction of energy use is an important goal in all scenarios, but water use was not specifically addressed (Torrellas et al., 2012).

Trade-offs between the nexus domains are also shown by research carried out at Wageningen University and Research, where inputs of water and energy, and tomato yield are compared across low-, mid- and high-tech production methods. Results are not unified and an optimal setup also depends on the local resource availability (Campen, 2017). Other trade-offs relate to seasonality, location and method of production. An assessment of carbon and water footprints of fruits and vegetables at a Swiss retailer found that air-freight is undesirable and non-local production only recommended when local greenhouses are fossil fuel powered (Stoessel, Juraske, Pfister, & Hellweg, 2012).

The analysis of diets in a specific region in the UK finds that embodied water is largely imported and embodied energy largely due to irrigation (Salmoral & Yan, 2018). Additionally, differences in modelling choices in different LCI databases are highlighted (Cucurachi, 2016), addressing the spatial and temporal variability of energy and water use during production.

An LCA of 21 national breads in the EU suggests that breads with the least ingredients are also the most sustainable options (Notarnicola, Tassielli, Renzulli, & Monforti, 2017). Recipes including only flour, yeast, vegetable oils and liquids such as milk, combined with flat or small shapes lead to shorter baking times and therefore lower energy requirements. However, the authors acknowledge the dependency of their results on differing electricity mixes, production efficiencies and ingredient imports in each country.

Several studies have addressed the preparation of meals in different contexts such as home-made, ready-made and prepared in catering environments (Baldwin, Wilberforce, & Kapur, n.d., 2011; Berlin & Sund, 2010; Calderón, Herrero, Laca, & Díaz, 2018; Jungbluth, Keller, & König, 2016; Saarinen et al., 2012; Schmidt Rivera, Espinoza Orias, & Azapagic, 2014). Ready-made are less desirable because of higher cooling requirements and additional packaging waste, but more favourable based on more effective processing. Local sourcing and organic production may result in higher impact where production and procurement contribute significantly across all impact categories. Animal products specifically add to GWP. Industrial preparation or home-cooking is preferable over catering or restaurants, mainly because catering environments are exclusively used for the purpose of serving food. Nevertheless, preparation contributions are negligible in restaurants where operational support is more impactful. Energy demand and water use are comparable to climate change and eutrophication respectively.

Beyond environmental impact, including nutritional value of meals were found to be challenging because indicators such as GWP and nutritional value for individual ingredients vary greatly and randomly (Saarinen, Fogelholm, Tahvonen, & Kurppa, 2017). While high-impact ingredients such as meat can be replaced with favourable alternatives, they are likely to be nutritionally inferior (Van Mierlo, Rohmer, & Gerdessen, 2017). In terms of water efficiency, it is always preferable to obtain any macro-nutrients through crop products (Mesfin M Mekonnen & Hoekstra, 2012).

In a recent study, a range of functional units (live weight, land use, price) were used to express the differences of impacts (Eutrophication, Climate Change, Land Use) between conventional and organic chicken and pig production systems in France. The study used background data from the AB database. The results indicate higher environmental impacts and product prices in organic production systems compared to conventional production systems. However, as prices rise more steeply compared to environmental impact values, a functional unit based on economic value is recommended for environmental labelling of food items. Value-conscious consumers are thereby likely to reduce their environmental impacts when spending the same amount of money (van der Werf & Salou, 2015).

2.3.1 Simplification of LCAs

There are opposing perspectives on food LCA strategies.

On the one hand, technical data can often be flawed for full LCAs, which supports a simplified method with better defined system boundaries. A method should be chosen to support the specific study goals and take available resources into consideration (Pernollet, Coelho, & Werf, 2017). Further, tailored methods may be necessary when variabilities in the food system can be better reflected through improvements of data quality and interpretation (Notarnicola, Sala, et al., 2017).

On the other hand, including consumer behaviour in the analysis may require more sophisticated and holistic methods. Adapting LCAs to include qualitative assessments of Nexus interactions can be challenging when there is a lack of quantitative data and because of the complexity of the method (Karabulut, Crenna, Sala, & Udias, 2017).

An assessment of BilanProduit, CCaLC and eVerdEE as tools to carry out simplified food LCAs compared to a full ReCiPe midpoint LCA highlights that all tools contain flawed methodologies. Only specifically designed tools can resolve recurring issues such as missing impact categories, incomplete databases or non-standardized modelling (Arzoumanidis, Salomone, Petti, Mondello, & Raggi, 2017).

2.4 Summary

The potential of environmental impacts from food provision has arrived on national and international policy agendas, which are based on increasingly robust scientific evidence. Such environmental impacts are numerous and various along the production and supply chain of foods. The scientific community has developed several methods to account emissions, although their robustness largely depend on the scope and goal of a study, quality of available data and the validity of results.

At the most basic level, where the purpose of a process revolves around the provision of organic material, the process system results in the use of water and the transformation of energy. Both factors have different consequences on the environment in terms of airborne and waterborne emissions. The Nexus perspective acknowledges the interdependencies between those three dimensions and supports strategies to reduce overall environmental impacts by optimizing the trade-offs between them. Fundamentally, a Nexus perspective provides a simplified representation of a system in terms of its water use, energy consumption and food yield. An optimal improvement of the system would see both water and energy requirements decrease while at least maintaining the same food yield. As such, this study distils the complexity of environmental impact assessment methods into simple results to allow a non-scientific audience understand the relative difference of environmental impacts from foods.

3 Research methods

This section defines the research approach and specifies the data collection and analysis methods applied in this study.

3.1 Approach

This study uses an inductive research approach and employs mixed methods. A remote survey establishes primary data which subsequently feeds into an LCA in combination with aggregated secondary data. The LCA results are then discussed regarding their suitability of application in an economic and socio-political context.

An inductive approach is considered more suitable for the variety of research questions and methods in this project. The general lack of robustness of food LCAs as discussed in section 2.3.1 also supports an exploratory rather than deductive approach based on an initial hypothesis.

Top-down data from two background databases complements the life-cycle inventory for the LCA in this study: ecoinvent 3.4 (EI) and Agribalyse 1.3 (AB). The former is an internationally recognised source of background processes, the latter is a farm-to-gate LCA database based on detailed information from the French agriculture industry.

3.2 Data Collection and Analysis Methods

3.2.1 Menu selection and recipe inventory

The primary data collection is supported by Stichting Duurzam Horeca Leiden en omstreken (Stichting Duurzame Horeca Leiden en omstreken, n.d.). The organization's members have substantial knowledge of Leiden's food scene and their survey has identified the 19 most popular dinner destinations in the city.

Assuming the economic law of supply and demand applies, the number of occurences of each dish across the menus of all 19 restaurants identifies the most popular options. In order to achieve a wide spread of available dietary options, the two most popular dishes in the following categories are selected for the study: red-meat-based meals (beef and pork), poultry-based meals, fish-based meals, vegetarian meals. Additionally, each category is complemented with a version of one of the dishes that would fall into the next category, i.e. poultry-based meals replace meat-based meals, fish-based meals replace poultry-based meals, vegetarian meals replace fish-based meals, vegan meals replace vegetarian meals.

Stichting DHLeo's recommended list of popular and suitable dinner restaurants in Leiden revealed which meals occur most frequently across all menus. Only identical or near identical meal descriptions counted towards occurrences. For each of the 4 meal groups – red-meat-based meals (beef and pork), poultry-based meals, fish-based meals, vegetarian meals – a web search informed the selection of alternative versions.

As each business uses proprietary recipes, any recipe can be used to identify the ingredients and preparation methods. To ensure a consistent standard of quality, recipes from a reputable online source such as 'BBC Good Food' (BBC, n.d.) were selected, based on a variety of factors such as relevance, generic ingredients and perceived ease of preparation.

A total of 76 ingredients make up the 12 meals and alternatives in this study.

Albert Heijn's online ordering prices from 15 July 2018 were used to calculate the ingredient cost for each meal and alternative.

The tabs 'MenuSelection' and 'RecipeInventory' (Claussner, 2019) contain the complete meal survey data and recipe inventory.

Occurrences	Meal	Cost [€]	Category
9	Beef Burger	1.51	Red meat-based meals
9	Spare Ribs	2.73	
6	Chicken Satay	1.64	Poultry-based meals
5	Roast Chicken	4.37	
9	Salmon Fillet	8.42	Fish-based meals
5	Codfish	6.43	
5	Lasagne (V)	1.69	Vegetarian meals
4	Goats Cheese Salad (V)	3.50	
	Alternative	Cost [€]	
	Turkey Burger	3.04	Meal category alternatives
	Salmon Satay	4.44	
	Tofu Fillet	3.05	
	Vegan Lasagne	2.22	

Table 3.1 - Most common dinner meals in Leiden on 10 June 2018, alternatives, ingredient cost, meal category

Out of the 19 surveyed restaurants, only 1 does not offer any of the 8 selected meals listed in Table 3.1. On average, the meal selection represents 26% of all menu options available at the surveyed restaurants.

The meal descriptors Beef Burger, Salmon Fillet and Spare Ribs occurred nine times each across all menus, making them the most popular dinner meal options in Leiden.

In terms of cost, the ingredients for meals in the category 'fish' are on average 2.6 times more expensive than across all other categories.

3.2.2 Ingredient definitions and conversion parameters

Albert Heijn is a common restaurant supplier in the Netherlands and lists ingredient prices on its website, as opposed to other wholesalers such as De Kweker. The ingredients form the raw data input for the LCA and may require conversion into suitable units. As the LCA follows a simplified method, any processed ingredients such as ketchup must be converted into suitable 'raw materials' such as tomatoes. In such cases, only the most relevant ingredient by mass is used as model input. Further, some ingredients are not available in the LCA background databases and must be represented by appropriate proxies.

During this phase, other classifications for water processing requirements and storage allowances are complied based on industry and research publications as much as possible. Non-scientific resources may be used where data gaps cannot be filled otherwise.

3.2.3 Modelling assumption, exclusions and calculations

3.2.3.1 Replacement ingredients

For the purpose of simplifying the LCA model, composite ingredients such as ketchup are represented by their most significant ingredient such as tomatoes. 14 of the 76 ingredients were converted into single replacement ingredients. The weight of the replacement ingredients was adjusted to reflect the required quantity to produce the composite ingredient. The conversion may skew the LCA model for individual ingredients such as the burger bun (BBC Good Food, n.d.), which contains seven ingredients but the model only accounts for flour as the most significant ingredient by weight. Additionally, the production of the composite ingredient is not accounted for such as baking burger buns, cooking and pasteurizing tomato sauce, fermentation and distillation of vinegars or alcohols. The basis for the calculations are given in the tab 'IngredientDefinition' (Claussner, 2019).

3.2.3.2 Proxy ingredients

The 76 ingredients are converted into 41 representative products that are available in the EI or AB databases. 29 ingredients are modelled by directly matching products systems.

Most notably, rapeseed is used as a proxy for the 10 ingredients in the herbs and spices category across all recipes. As a plant of the 'Brassica' genus in the 'Mustard' family, rapeseed is the only suitable product in either background database to serve as a proxy for herbs and spices in this simplified LCA model.

Where there are several option for the production country of a proxy ingredient that is not the Netherlands, a web search is performed to identify the highest exporting country of this product to model a realistic supply chain.

The French agriculture system is considered comparable with the Dutch (D'Amico, Coppola, Chinnici, Di Vita, & Pappalardo, 2013). Therefore, proxy ingredients from the AB database are treated as if they originate from the Netherlands.

3.2.3.3 Auxiliary inputs during processing, storage and preparation

3.2.3.3.1 Water

All ingredients are associated to the categories listed in Table 3.2.

Category	Water consumption [kg/kg]	resource
Alcohol Refining	24	(Doorn et al., 2006)
Beer & Malt	6.3	
Coffee	n/a	
Dairy	7	
Meat & Poultry	13	
Starch Production	9	
Sugar Refining	n/a	
Vegetable Oils	3.1	
Vegetables, Fruits & Juices	20	
Wine & Vinegar	23	
Fish	11 – maximum value used	(World Bank Group, 2007)

Table 3.2 - Water consumption for industrial processing per food category

For the preparation of meals, a water consumption of 3 litres/kilogram only applies to the vegetable ingredients of each meal and alternative (Lehto, Sipilä, Alakukku, & Kymäläinen, 2014). The water consumption of other ingredients is not considered in this model for lack of reliable data.

The ReCiPe impact assessment method calculates WDP values based on depleted water resources and not total abstracted water. Abstracted water can return to a natural resource in the same location without industrial processing and therefore not count as depletion. During processing and preparation of food, effluent is always directed to waste water treatment operations and therefore not returned to the resource from where it originates. As such it is acceptable to combine WDP values that result from the food cultivation with the abstraction (or consumption) values that relate to processing and preparation.

3.2.3.3.2 Transport

Based on the European Commission's data of utilised agricultural area (eurostat, 2010), the productivity-weighted average distance for products sourced within the Netherlands delivered to Leiden is 142km, as shown in tab 'OtherParameters' (Claussner, 2019).

All products are considered to be stored or processed in either of the Netherlands' food hubs Amsterdam and Rotterdam, thus adding 40km to the distance of delivered ingredients to restaurants in Leiden (Pinckaers & Phillips, 2018).

The transport of proxy ingredients that are produced outside of the EU is modelled as transoceanic freight shipping. Distances are based on shipping routes from the respective country's busiest freight port into Rotterdam (SEA-DISTANCES.ORG, 2019). For consistency of modelling choices. where a proxy ingredient is modelled as 'Rest of World' or 'Global', the average of 10586km (Claussner, 2019) of all other shipping routes in this model is used.

3.2.3.3.3 Energy

Energy consumption for processing and storage is modelled as refrigeration requirement for the ingredients' recommended maximum refrigerated shelf-life. The effect of the maximum shelf-life is compared with the effects when the refrigeration duration is reduced to 50% and 10%. This approach reflects qualitative diversity of restaurant meals which are often associated with the freshness and seasonality of ingredients (Richard Keys, 2013; Will Martin, 2018). While the shelf-life of perishable ingredients is already short and a reduction in refrigeration duration will have a limited impact, the consistent reduction of refrigeration duration across all ingredient types may provide relevant insight for whole meals.

Under these conditions, the model assumes the longest possible storage period and therefore the largest possible contribution from refrigeration during storage.

Factor	Quantity	Resource
Ingredient density – determines space requirement	Variable [l/kg]	(Charrondiere, Haytowitz, & Stadlmayr, 2012)
Typical storage setup	2m shelf height 10% aggregated space utilization	(United States Department of Agriculture, 2016, p. 15) (Manikas, Terry, & Terry, 2009)
Typical building setup	30 years design life 11500m2 plant floor area	(Designing Buildings Ltd, 2018) (Food Engineering Mag, 2018)
Recommended maximum refrigerated product shelf-life	Variable [hrs]	(Albrecht, 2007)
Cooling energy requirement	0.103 [MJ/hr/l] of stored food	(Engineering ToolBox, 2003b; Evans et al., 2014)

Table 3.3 – Refrigerated food storage parameters

Energy consumption of meal preparation is based on average data of food preparation appliances and specific cooking times as defined in the recipes.

The operational load utilization of 26% in electric ovens between the hours of 10am and 10pm results in an average output of 2.86kW. Utilization of 74% in gas appliances between the hours of 10am and 10pm results in an average output of 6.81kW for hobs and 15.54kW for grills/fry-tops (AEA, 2012; Mudie, Essah, Grandison, & Felgate, 2016). The Dutch gas grid is largely fed by the Groningen gas field, which contains mainly methane at an average energy density of 37.8 MJ/m3 (Correljé, Van Der Linde, & Westerwoudt, n.d.; Engineering ToolBox, 2003a).

The tab 'RecipeInventory' (Claussner, 2019) contains the specific cooking times and conditions for each recipe.

3.2.3.4 Alternative scenarios

Table 3.4 shows the alternative proxies across the two background databases that are used to assess the various scenarios.

Proxy ingredient	Baseline Scenario	Alternative Scenarios	
		Organic production	Alternative database
Carrot	EI – Netherlands		AB – France, national average
Broiler	AB – France, national average	AB – France, organic	EI – GLO
Cow milk	EI – Rest of World (RoW)		AB – France, national average
Egg	AB – France, national average	AB – France, organic	
Fava bean	EI – RoW	EI – RoW, organic	AB – France, national average
Grape	EI – Global average (GLO)		AB – France, national average
Maize starch	EI – Germany		AB – France, national average
Potato	EI - RoW	EI – RoW, organic	AB – France, conventional
Rice	EI - China		AB – Thailand, national average
Rapeseed	EI - RoW	EI – RoW, organic	
Soybean	EI – United States	EI – RoW, organic	
Tomato	EI - Netherlands		AB – France, conventional
AFFECT RATE		18/76	19/76

Table 3.4 - Proxy characterisation for alternative scenarios

3.2.4 Life-cycle inventory

3.2.4.1 Scope and goal

The scope of the LCA is a farm-to-fork system with a focus on differentiation between ingredients and meals along the procurement and preparation stages. It's functional unit is the 'consumption of 1 main course in a Leiden restaurant'. The system boundary and relevant flows are shown in Figure 3.1 below.

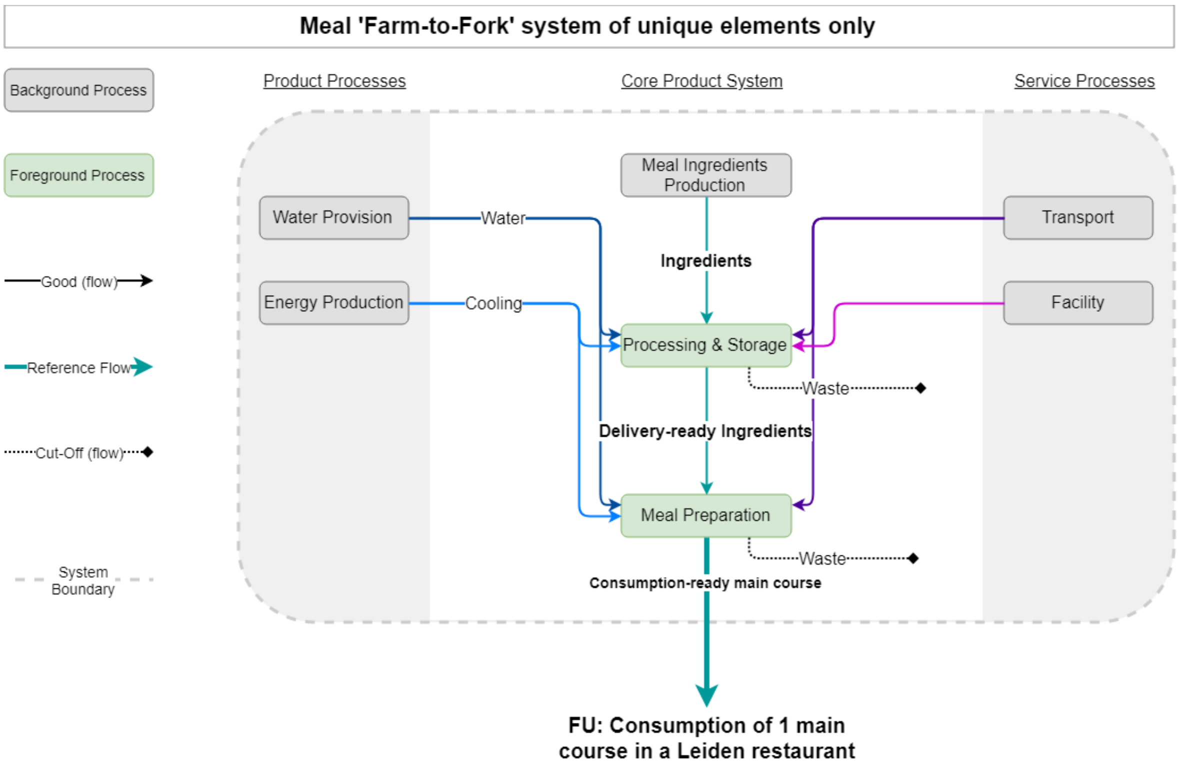

Figure 3.1 - LCA product system diagram

The goal is to compare the meals in terms of the Nexus-relevant impact indicators 'cumulative energy demand' (CED) and 'water depletion potential' (WDP). Both indicators highlight permanent changes or reductions in available resources within an area of availability. This aligns with the IPCC's definition of a global temperature rise of more than 1.5 degree Celsius beyond pre-industrial levels as the point where permanent or irreversible changes of the global climate will take place (Hoegh-Guldberg, Jacob, & Taylor, 2018). Further 'water depletion potential' is considered a more appropriate impact assessment method compared to Water Footprints or water demand. Sophisticated technological cultivation methods such as hydroponics and aquaponics achieve a high rate of nutrient cycling which removes issues around eutrophication of effluent waters, leaving the absolute removal of water resources from a catchment area as the most significant measure of environmental impact related to water use (Metabolic, 2018a)

More specifically, only aspects that distinguish the production and provision of ingredients and preparation of meals from each other are included in the product systems. As such, the following aspects are excluded:

- Packaging – does not directly relate to the food products. These may be supplied fresh and directly from the producer and make use of resusable packaging, which is considered to be substantial research in its own right and outside of the scope of this study (Han, Ruiz-Garcia, Qian, & Yang, 2018)
- Food Waste – based on the large uncertainty of data (FAO, 2011), food waste is considered consistent throughout the supply chain and therefore affects overall magnitude but does not differentiate meals when comparing their impacts
- Seasonality of produce, production efficiency and long-haul supply – the trade-offs between seasonally and locally sourced food products and out-of-season long-distance supply of food products are mostly negligible (DEFRA, 2012)

- Restaurant fitout and operation – these are considered identical for all dishes and therefore do not affect comparable meal-specific impacts. However, operational impacts are considerable across the whole life-cycle in the context of food consumption in restaurants (Baldwin, Wilberforce, & Kapur, 2009). As the fit-out is beyond the choice of the customer, it is outside of the scope of this study

The EI database provides background data for non-food products and services as well as most ingredient production systems. EI data is modelled in CMLCA software version 6.1. Where ingredient production systems are not available in EI, background data from the AB database is modelled in openLCA software version 1.7.2.

Compatibility and licensing restrictions prevent the processing of both databases in either software. However, the same impact assessment method is applied in both tools which enables direct comparison of initial results and further calculations outside of the tools.

3.2.4.2 Scenarios

Four scenarios are compared in this study.

A 'baseline' scenario consists of products that are modelled according to the following hierarchy

- Product system refers to the Netherlands
- Product system refers to a location that is comparable to the Netherlands (i.e. Germany, France, Spain)
- Product system refers to another location that is a significant exporter of the product
- Product system refers to 'rest-of-world' (RoW) or global (GLO) averages

The second scenario is aligned with food product information that is generally accessible to the consumer addresses changes of impacts. It compares the baseline's default of industrial food production with organic alternatives.

In the third scenario, variations of impact results from matching product systems in the two LCA databases are investigated. This scenario forms part of the sensitivity analysis of the model.

A fourth scenario is built into the model where alternatives for each meal group are assessed, as outlined in 3.2.1.

3.2.4.3 Inventory analysis

The inventory analysis includes a comparison of direct results from the databases with other relevant publication such as Water Footprints as well as direct results with aggregated results for delivery-ready ingredients. The inventory analysis is conducted outside of CMLCA and openLCA so that results can be consolidated and cross-referenced.

3.2.4.4 Impact assessment

Recipe 2008 midpoint assessment is applied in both software tools to obtain WDP at production, provision and preparation stage. The method excludes green water as per the assessment method's definition (Goedkoop et al., 2009). CED is a standalone impact assessment method which provides granular information related to various energy production methods, aggregated at a national level.

Both assessment methods are applied to the background data at production level for ingredients and associated products and services. Thereafter, results are consolidated and extrapolated outside of the LCA software.

Across all backgroup products uses in this study, the relationship between impact indicators CED and GWP100 is amost identical as shown in Figure 3.2 belowError! Reference source not found.. This dynamic confirms that CED is a suitable screening indicator and can replace GWP100 when food items are modelled for comparison and refer directly to background databases. This observation is particularly useful in the context of the Nexus which explores relationships between water, food and energy consumption, and is not limited to greenhouse gas emissions as a metric. While the decarbonisation of energy systems progresses, renewable energy technologies depend on rare earth metals which lead to a different set of environmental and social impacts. To that end, assessing energy demand, regardless of it's production method, captures a wider range of potential impacts than by accounting greenhouse gas emissions only in form of GWP.

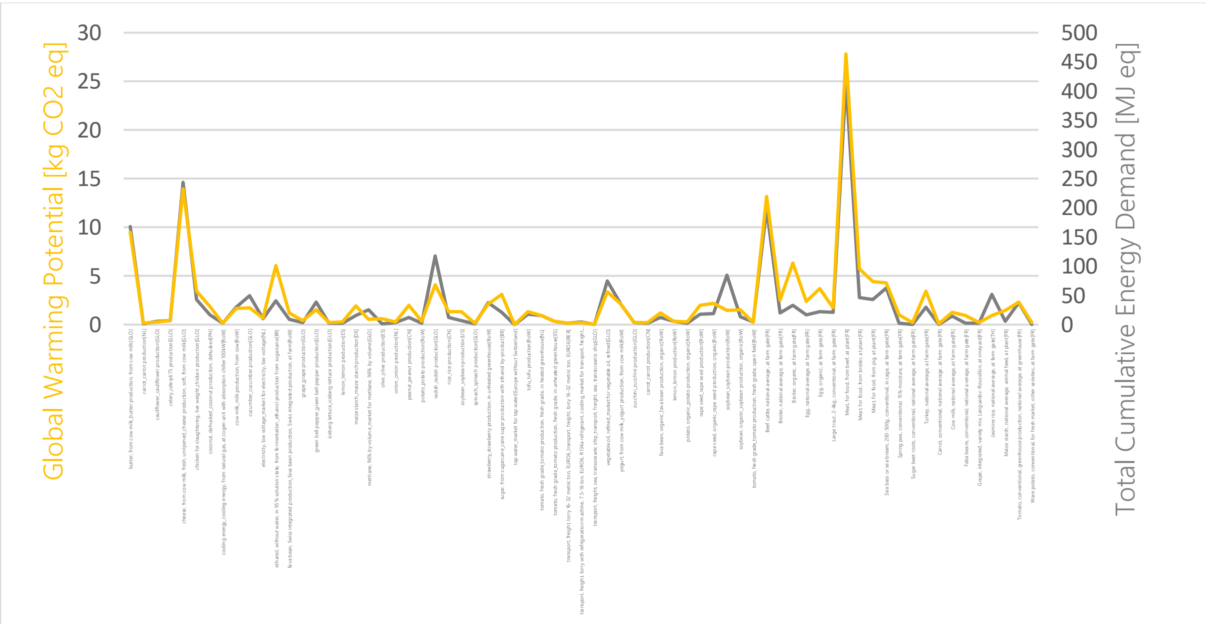

Figure 3.2 - Comparison of GWP100 vs CED for food ingredients from databases

3.2.4.5 Sensitivity Analysis

The LCA's sensitivity analysis is based on several modelling assumptions.

Physical allocation of multi-functional processes is used as default in the model. However, portion sizes vary, so meals are normalized to an average portion mass of 500g to compensate for high uncertainties around potential side orders with each meal and a limitation within the model setup that currently only accounts for the main meal ingredients and preparation method.

The model includes assumptions about cooling requirements. The default model setup calculates impacts when perishable and semi-perishable foods are industrially refrigerated for their maximum shelf life. The impact of this assumption on the results are tested by reducing the storage duration to 50% and 10% of the maximum shelf life across all refrigerated ingredients.

3.2.5 Reliability, validity and generalizability

The analysis of LCA results are assessed for their academic integrity to allow stakeholders to make well-informed decisions.

3.2.5.1 Replicability

The reliability of the study is based on well documented sources for all data used in the model. Data must be replicable and all modelling decisions are clearly documented. Trade-offs between attainability and accuracy of data are discussed with the aim to show that the results are valid within the scope and goal of the study. For the purpose of validation, results are frequently compared against other resources such as the Water Footprint and existing LCA studies.

Generalizability will depend on how well the primary data can be integrated with the aggregated data from other sources, but the study's main focus is on the locally available choices and should be generalizable to comparable dishes, restaurants and locations in NL at least.

3.2.5.2 Problems with the data

The data that supports the model is of various quality, density and level of aggregation. Some modelling assumptions cannot be tested for validity, as is the case with replacing proxy ingredients with alternative background products due to limitations in products that are available in either database. Extrapolation of significant insights across all ingredients and dishes may be necessary for consistency, but will also likely increase uncertainty. Therefore, patterns in the results need to be treated with caution.

Within the limitations of this study, the results may not reflect optimal choices for a healthy diet, as nutritional value is not included in the model.

3.2.5.3 Scaling

The purpose of this study is to generate water and energy impact calculations as conveniently as possible, while remaining scientifically acceptable. As such, the methodolgy should be applicable to any other restaurant in any other enviroment, as long as appropriate parameters are employed when modelling the supply chain.

The model in this study only considers two impact indicators. The LCA results may confirm whether the model would benefit from being complemented with further indicators to make the model more robust. Ignoring impacts related to land-use may be particularly relevant in densely populated and highly technizised countries such as the Netherlands.

Scaling of the model to a larger system boundary will present challenges in terms of selecting appropriate meals. However, such aggregated data will reduce the relevance to local stakeholders and dilute the effect of the top-down and bottom-up approach.

Aspects currently excluded from this study (see 3.2.4.1) may have significant social, ethical, economic and environmental impacts.

4 Results

In this chapter, the quantitative variables, parameters and results are disseminated.

This section contains the results of the LCA, which is based on the aforementioned survey and modelling choices.

Figure 4.1 shows the LCA results after normalization with 2014 factors for ReCiPe 2008 (Goedkoop et al., 2014). The data represents each meal's contribution to the average total annual impact generated by a person in the EU in the year 2000. No normalization method is available for CED, which therefor not included (Acero, Rodríguez, & Changelog, 2015).

The Beef Burger meal's normalized impact is highest at 0.07% and approximately 7 times larger than the next most impactful meal, Codfish at 0.01%. Based on the results, the consumption of 1,428 Beef Burgers per year would generate the average annual total impact per person. At the other end of the spectrum, a person could consume 100,000 meals of Tofu Fillet to generate the same total impacts.

The highest contribution among impact categories can be seen for 'freshwater eutrophication', which ranges between 75 and 95% for almost all meals. The exceptions are the Lasagne meal, where Ricotta cheese makes 'natural land occupation' the largest contributing category with 60%, and the Tofu Fillet meal, where the contributions are more distributed across several impact categories. The significance of impacts generated from cheese production is illustrated by the fact that the normalization factor for 'natural land occupation' is 62% lower than the normalization factor for 'freshwater eutrophication', but the normalized impact value is 4-times higher than for 'freshwater eutrophication'.

The normalization factor for 'freshwater eutrophication' is 0.41, while the average of factors across all included impact categories is 1,496.56 and the median is 34.37. This highlights the disproportionally high contribution of 'freshwater eutrophication' and its relevance to the overall impact scores of the meals. For the Beef Burger meal, this means that the normalized value for this impact category is 17-times above the average annual impact in this category per person in the EU in the year 2000. The only other meals that result in normalized values for 'freshwater eutrophication' above 100% (= one year worth's of generated average impact per person) are Roast Chicken, Spare Ribs and Codfish.

Other than 'freshwater eutrophication', no other impact category yields values above 100% across all meals.

The normalisation results shown are based on regional environmental impact data, which can be highly variable and are usually limited in their robustness (Aymard & Botta-Genoulaz, n.d.).

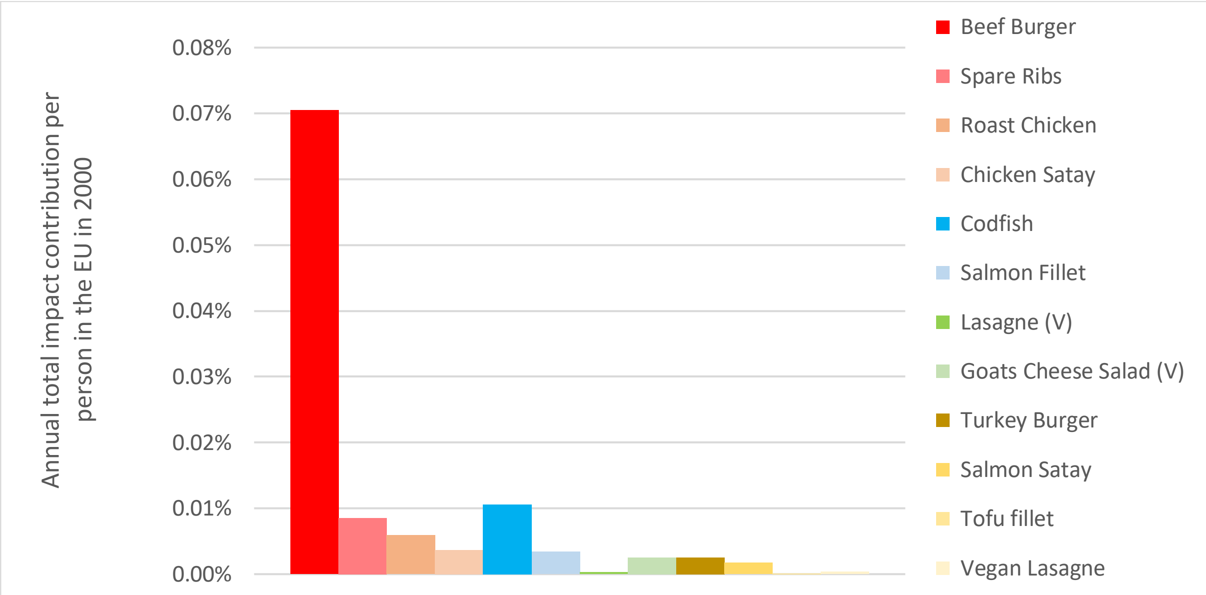

Figure 4.1 - Normalized meal impacts (excluding CED), 2014 factors for ReCiPe 2008

Figure 4.2 provides an overview of the full relative LCA results for all meals in this study. Contributions towards impact indicators are relatively consistent across all meals. The exceptions are 'agricultural land occupation', 'freshwater eutrophication', 'marine eutrophication' and to a lesser extent 'human toxicity' and 'terrestrial ecotoxicity'. Here, Beef Burger results in significantly higher impacts than compared to all other indicators. Freshwater and marine eutrophication are directly linked to water resources, but those significant impacts would not be captured by WDP. The next most significant inconsistency of 'agricultural land occupation' relates to an additional dimension that is increasingly included in Nexus research, but also not included in this study. In addition, the following observations can be made:

- Beef Burger results in higher impacts across all indicators compared to Spare Ribs
- Goat's Cheese Salad results in higher impacts across all indicators compared to Vegetarian Lasagne
- Roast Chicken and Codfish consistently result in the highest impacts
- The group of 4 alternatives (shades of yellow) make up 33% of all dishes, but rarely achieve combined impacts of more than 20%
- Salmon Satay consistently result in the highest impacts out of the group of alternatives

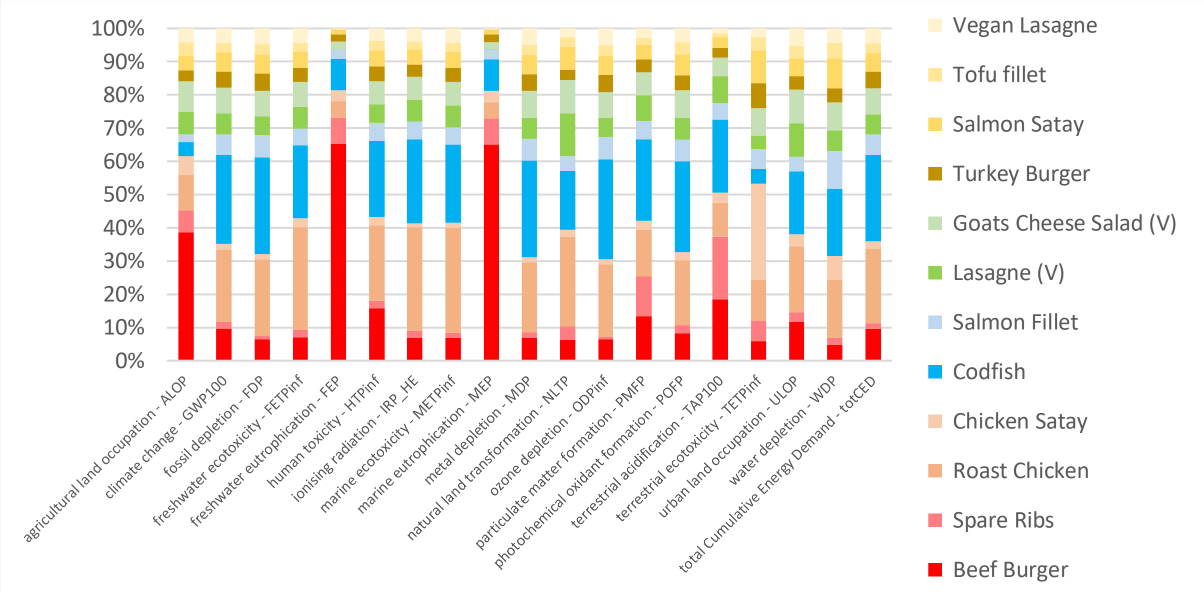

Figure 4.2 - Relative LCA results for all meal options across all ReCiPe impact indicators and total Cumulative Energy Demand

4.1.1 Baseline and normalizes results

The baseline results in Table 4.1 illustrate WDP and CED impacts for each meal. The purchasing cost of ingredients for each meal is also included.

RQ 2 - Table 4.1 and the subsequent section detail the WDP and CED impact results from a farm-to-table LCA study of popular dinner meals in restaurants in Leiden

Meal	Cost [€]	WDP [litres]	CED [MJ]
Beef Burger	1.51	75.20	147.86
Spare Ribs	2.73	32.76	28.23
Roast Chicken	4.37	279.93	348.83
Chicken Satay	1.64	117.90	38.23
Codfish	6.43	314.61	401.13
Salmon Fillet	8.42	184.35	95.00
Lasagne (V)	1.69	81.90	74.70
Goats Cheese Salad (V)	3.50	126.31	115.87
Turkey Burger	3.04	68.34	81.03
Salmon Satay	4.44	107.67	56.74
Tofu fillet	3.05	99.44	65.26
Vegan Lasagne	2.22	78.27	97.01
Meal Category – average values			
Red Meat-based meals	2.12	53.98	88.04
Poultry-based – meals	3.01	198.91	193.53
Fish-based meals	7.43	249.48	248.07
Vegetarian meals	2.60	104.11	95.28
Meal category aternatives	3.19	88.43	75.01
ALL MEALS average	3.59	130.55	129.07

Table 4.1 - Baseline impact results and costs

Codfish and Roast Chicken cause the highest impact across both indicators, while the ingredients for Salmon Fillet and Codfish incur the highest purchasing cost.

Spare Ribs yield the lowest WDP and CED results, while Beef Burger yields the lowest ingredient cost.

At the level of categories, Red Meat-based meals come at the lowest ingredient cost, lowest WDP impact and second lowest CED impact. Fish-based meals show the highest values across both indicators and come at the highest ingredient cost.

Impact results vary significantly across the meal categories red meat-based, poultry-based and fish-based, while meals in the vegetarian and meal group alternatives categories show closely aligned and generally lower values for both costs and impact indicators compared to the average in the study (Table 4.1).

Figure 4.3 and Figure 4.4 illustrate the LCA results for WDP and CED respectively when normalized to 500g portions. Normalized values follow a similar dynamic as raw results, except that Salmon Satay now displays highest WDP value across all meal options with an increase of 112%. The impact of Spare Ribs increases by 86%. Roast Chicken and Codfish show the largest changes across both indicators with reductions of 35% and 33% respectively.

This adjustment is an indicator of the relative meal sizes in this study, which primarily reflect the selected recipes. Although not immediately relevant to this study, meal mass can be used as indicator of energy content and energy density (Roberts et al., 2018).

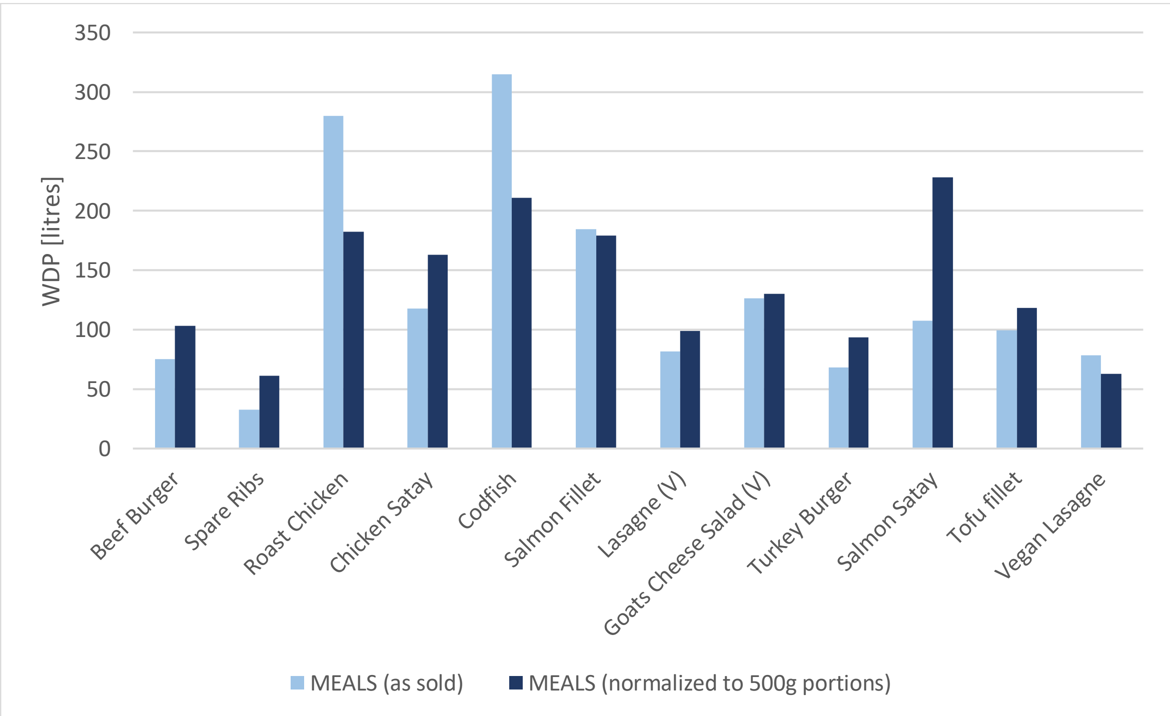

Figure 4.3 – WDP baseline vs normalized results

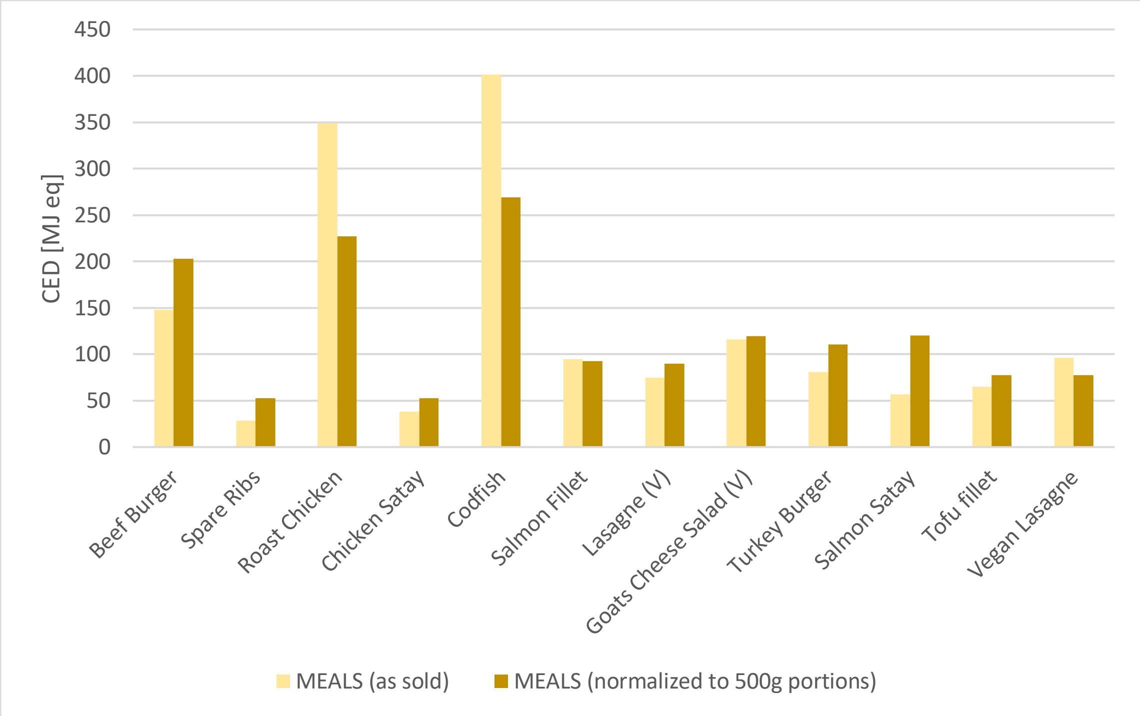

Figure 4.4 - CED baseline vs normalized results

4.1.2 Scenarios

Two scenarios in this study are determined by changes to the 12 proxy ingredients listed in Table 3.4. The 'organic' and 'alternative database' scenarios affect 25% of all ingredients in this study. The effects are presented in Table 4.2 below.

Scenario	WDP [l]				CED [MJ]			
	Max	Min	Average	Median	Max	Min	Average	Median
Organic production	188.7	-35.0	31.5	-18.0	152.6	-0.1	21.1	9.8
Alternative database	543.5	-86.4	34.5	4.2	140.4	-47.2	8.2	-4.8

Table 4.2 - Change of impact indicators in percent compared to baseline scenario across delivery-ready ingredients

The average changes in impact results that originate for the proxy ingredients are applied to all ingredients in each scenario. Figure 4.5 and Figure 4.6 show that WDP values only decrease under the 'organic' scenario for codfish. This result is due to the large share (by mass) of potatoes in this meal, where the organic production system in the same spatial boundary (RoW) yields a WDP value that is lower by one magnitude. Variations in the 'database' scenario are related to lower impact values from rice for Chicken Satay and more significant increases of impacts from broiler compared to decreases from potatoes for Roast Chicken.

Roast Chicken and Codfish both show the smallest increases of CED in the 'organic' and 'database' scenarios. The small change in CED from potatoes in the different scenarios has a significant impact on those two meals overall, as they contain a large share of potatoes (by mass).

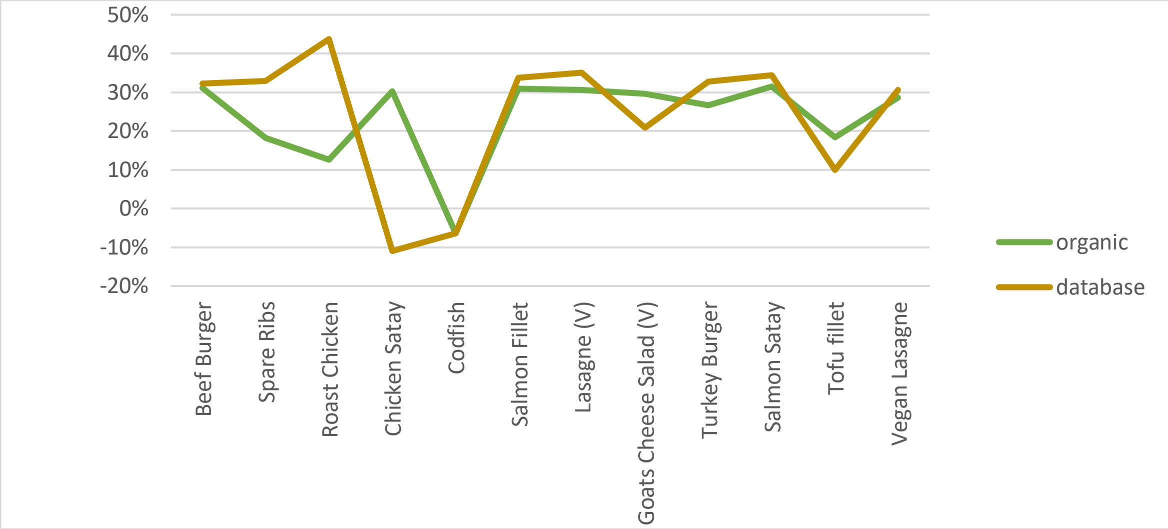

Figure 4.5 - WDP impact changes for scenarios compared to baseline results

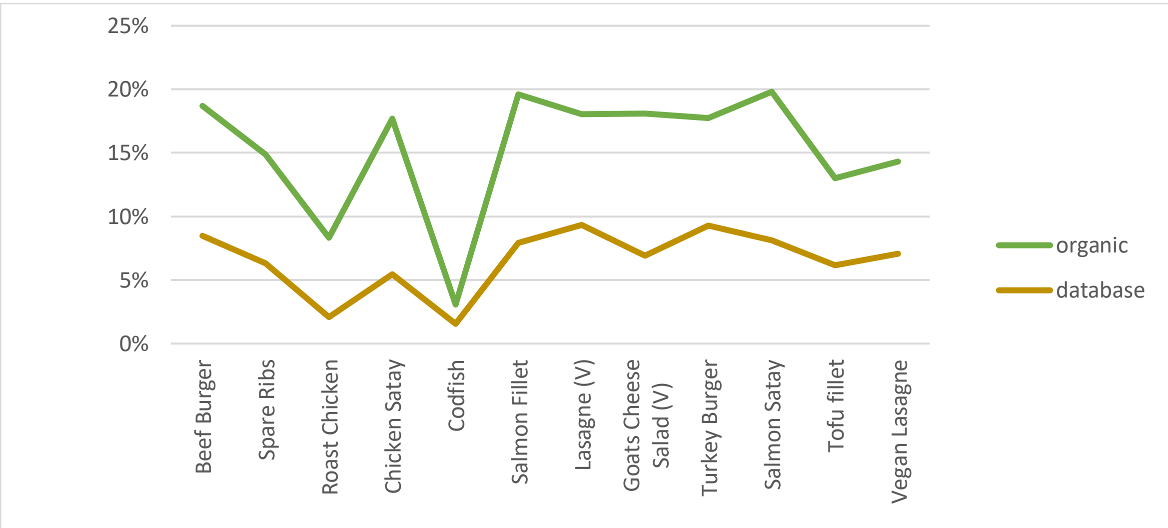

Figure 4.6 - CED impact changes for scenarios compared to baseline results

4.1.3 Contributions

In the baseline scenario, several upstream processes and products contribute to the environmental impacts when assessing both whole meals and individual ingredients.

For ingredients, the processing inputs of 'transport' and 'building' have negligible effects on WDP. For CED, 'transport' only shows significant contributions to ingredients that don't require cooling during storage. Otherwise, CED contributions are indirectly proportional to the product density, where cooling energy requirements are determined by the volume of 1kg of product and its maximum shelf-life. As a result, the CED contribution from cooling reaches almost 100% for lettuce, mixed leaves, onions, potatoes and spinach. In this model, the contribution of production to WDP is below 10% for only seven ingredients, while the average is 56% across all ingredients. For CED, the contribution from production is below 10% for 20 ingredients, while the average is 49% across all ingredients. Figure 4.7 and Figure 4.8 illustrate the relative dominance of production (green) and cooling (orange) as consistently largest contributors to both impact indicators at the 'Processing & Storage' stage.

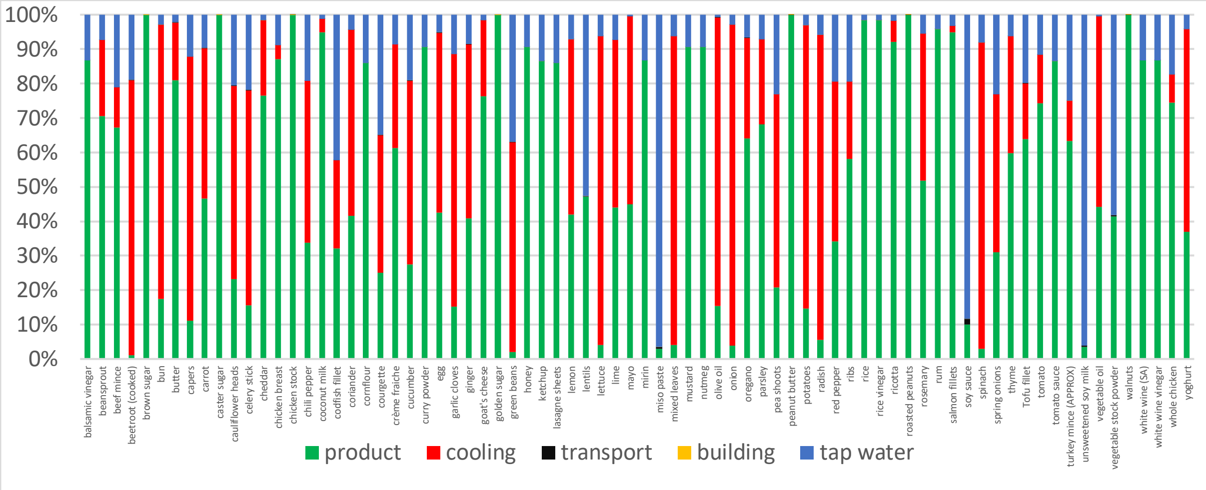

Figure 4.7 - WDP contributions to delivery-ready ingredients - baseline scenario

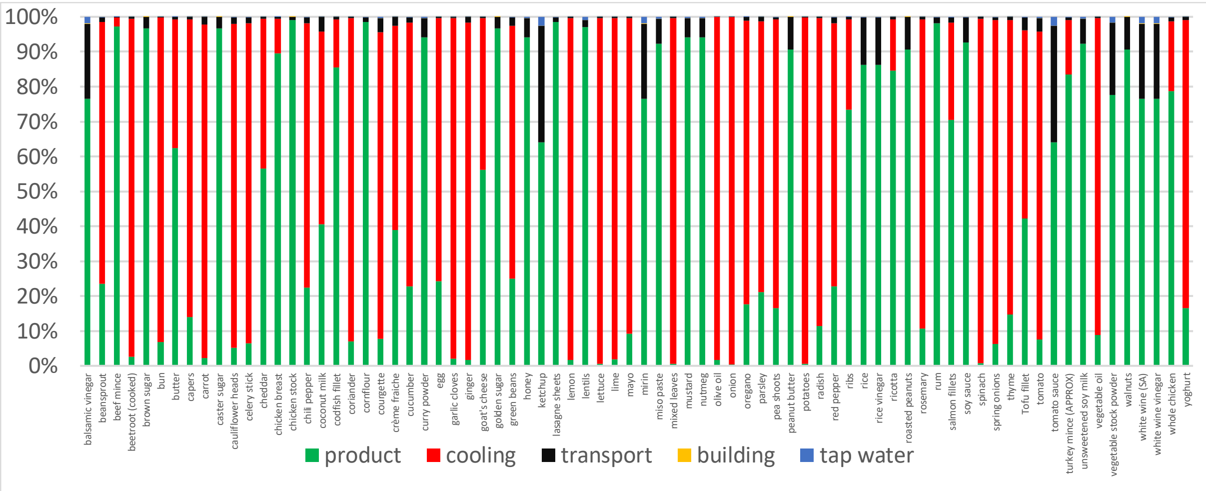

Figure 4.8 - CED contributions to delivery-ready ingredients - baseline scenario

For meals, impact contributions behave similarly across both measured indicators. In most cases, contributions are dominated by less than four elements, which are usually ingredients rather than secondary inputs during the 'Preparation' stage. Examples are shown below.

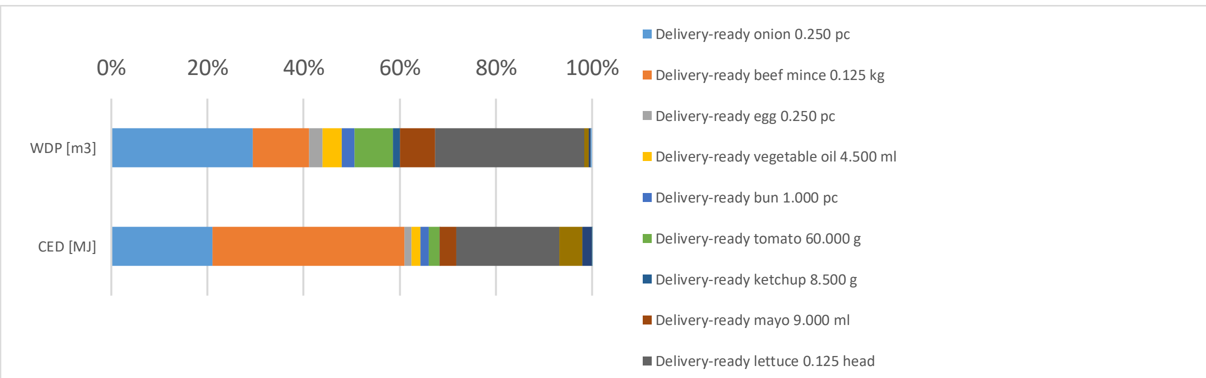

Figure 4.9 - Beef Burger: largest contributors are beef mince, lettuce, onion

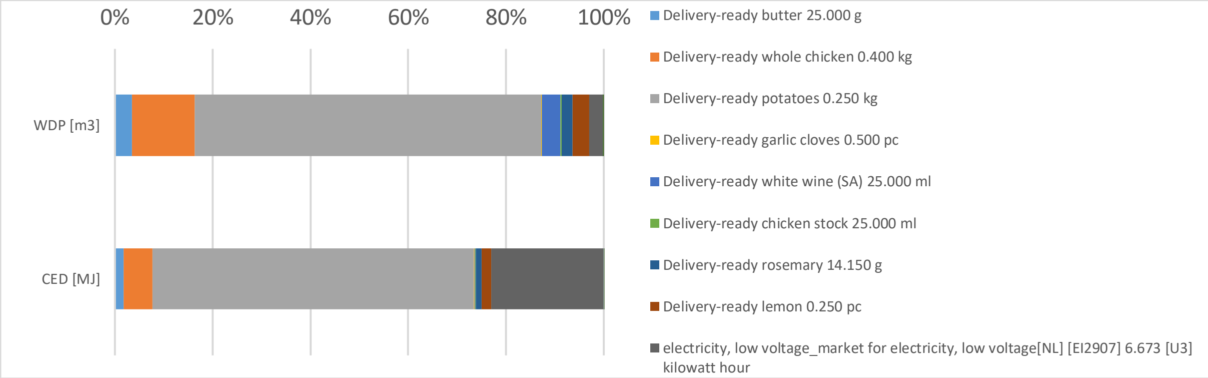

Figure 4.10 - Roast Chicken: largest contributors are potatoes, chicken, electricity

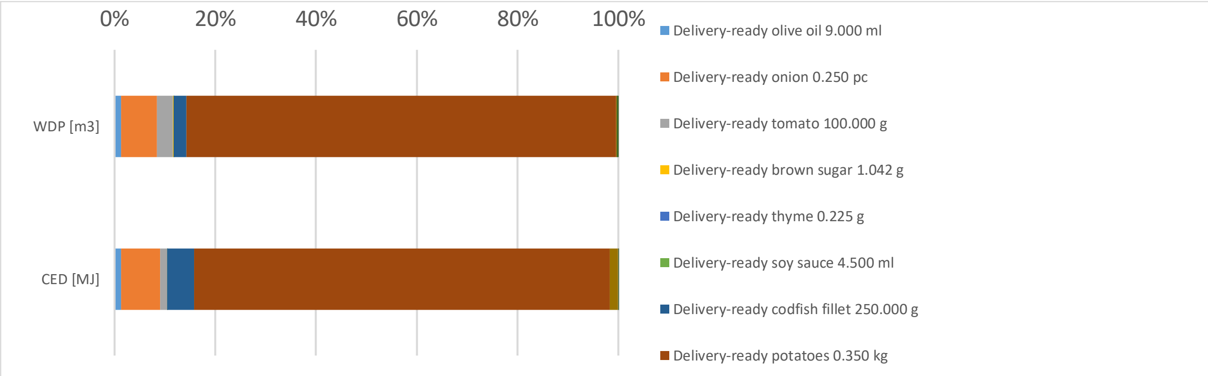

Figure 4.11 – Codfish: largest contributors are potatoes, onion, codfish fillet

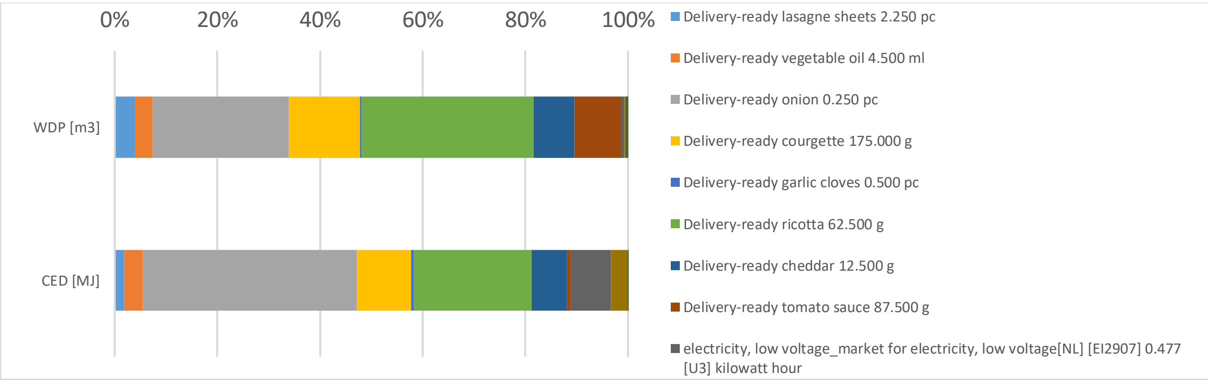

Figure 4.12 - Lasagne: largest contributors are onion, ricotta, courgette and cheddar

This pattern holds true regardless of number of ingredients. Exceptions are Chicken Satay and Tofu Fillet where the contributions are less concentrated. In this model, inputs that are associated with the preparation of meals (electricity, gas, transport, water) exceed a WDP contribution of more than 5% only twice out of 48 instances across the 12 meals. CED contributions exceed 10% five times, of which three instances are above 20%. The average contribution of preparation-related inputs are 0.7% for WDP and 2.6% for CED. A significant difference in contributions can be observed when comparing Salmon and Cod, which have been modelled from the AB background processes *trout* and *seabass* respectively. In comparison, *trout* is a land-based production system which is more water-intensive due to artificial ponds, while *seabass* is an ocean-based production system which is more energy intensive due to fishing vessels.

4.2 Analysis

This section addresses the robustness of the modelling choices and results.

4.2.1 Internal and external discrepancies

4.2.1.1 Recipe composition

The descriptors of several menu items across all surveyed restaurants do not inform conclusively about the meal's macro-nutrient composition. As a result, the recipes for this study vary in terms of protein-starch-fibre ratios. The recipes for Salmon Satay and Spare Ribs do not contain a significant amount of starch or fibre, while the recipe for Vegan Lasagne does not contain any significant amount of protein and the recipe for Salmon Fillet does not any starch. These discrepancies are also reflected in the total meal weights.

4.2.1.2 Background databases

Both background databases follow the same modelling principles in accordance with ISO 14044 (ecoinvent, 2017; Koch & Salou, 2016). While the background databases are utilized in separate software tools, identical characterization methods and factors are applied to background processes in both modelling environments.

AB includes custom allocation factors for all multifunctional processes. As an example, the process 'SPA C3-fat, from beef, at plant' also generates 'Meat, for food' as an output, which physically constitutes 45% of all outflows. However, 93.95% of emissions from the process are allocated to this product. A similar relationship is the case for the products 'maize starch', 'meat from broiler' and 'meat from pig', where the difference between the AB custom default allocation and a physical allocation of emissions ranges between -11 and -56%, as shown in tab 'Allocations' (Claussner, 2019).

In CMLCA, several EI product systems that are relevant to this study include multi-functional processes. In such cases, by-products are modelled as waste and cut-off. As a result, 100% of emissions are allocated to the product that is relevant to this study. One such example is process P3652 which produces 1kg cow milk, 0.614kg solid manure and 2.32kg liquid manure. While manure is commonly used as fertilizer (Yan, De Buisonjé, & Melse, 2017) or can be used in biogas production from anaerobic digestion (FAO, n.d.), the manure flows in this process are not considered functional and thus no emissions are allocated to them.

4.2.1.3 Other metrics for water

There are significant discrepancies between the WDP values from this study's LCA results and the corresponding Water Footprint values. Water Footprint data is not available for organic production systems and marine food products.

The largest differences occur for fava beans (RoW & FR) and soy beans (RoW), while all other discrepancies range between -100% and +3358%. When excluding fava and soy beans as outliers, the average difference is 3.76 times and the median difference is 1.13 times between WDP and Water Footprint. Differences of Water Footprint values between French and Dutch products range between -89.5% (tomato) and +75% (sugar beet root), with the exception of grapes at +538.9%.

These discrepancies raise questions about which methodology is more appropriate to analyse water-related impacts for the purpose of communicating scientific data to the general public. While Water Footprint calculations include all forms of water that affect the creation of a product, the ReCiPe methodology in an LCA model only accounts for the depletion of water resources that can be controlled by humans.

4.2.2 Sensitivity

4.2.2.1 Normalized results

Normalization of the LCA results to 500g meal portions reduces the range of results by 37% for WDP and 42% for CED, which also indicates a significant variation in portion sizes by mass. The overall pattern of impact results remains the same after normalization across all meals (Figure 4.3 & Figure 4.4) with the exception of Salmon Satay now scoring highest for WDP and Beef Burger more similar to Roast Chicken and Codfish in terms of CED.

4.2.2.2 Scenarios

The two alternative scenarios affect a different number of ingredients (Table 3.4). The changes range from a 4-fold increase (Whole Chicken, WDP, 'database' scenario) to a decrease of over 85% (white wine vinegar/mirin/white wine (SA)/balsamic vinegar, WDP, 'database' scenario). At an average level across both indicators, the 'organic' scenario (+25.8%) show results in marginally higher impacts compared to 'database' scenario (+21.4%).

In tab 'ScenariosIngredientImpact' (Claussner, 2019), a notable pattern can be seen in the background models of protein-rich ingredients such as chicken, eggs and soybean-based products, which all yield significant increases across both indicators in the 'organic' scenario, most notably for WDP at over 140%.

4.2.2.3 Meal group alternatives

Alternative meals for each meal group are meant to represent an option with lower environmental impact. The Turkey Burger as an alternative for the red meat-based meal group achieves an 8-9% reduction of CED, but scores 26-30% higher for WDP. Salmon Satay and Tofu Fillet as alternatives for the poultry-based meal and fish-based meal groups consistently reduce impacts between 39% and 73%. Vegan Lasagne as an alternative to the Vegetarian group reduces WDP impacts by around 25% and slightly increases CED values.

On average, the meal group alternatives represent a decrease of impacts between 23.8 and 37.9% as shown in Figure 4.13 below.

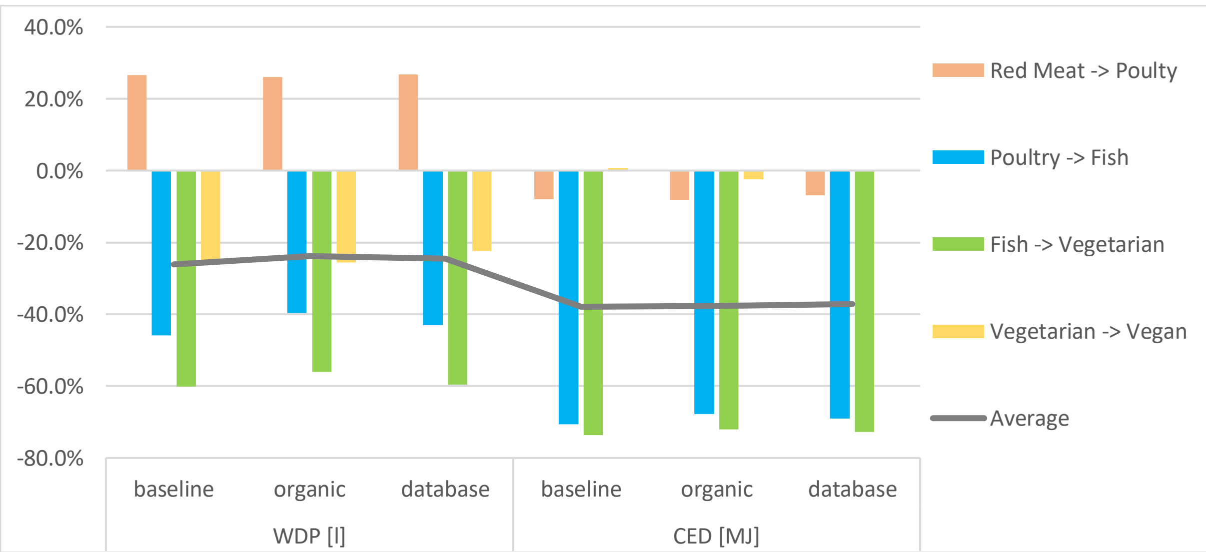

Figure 4.13 - Relative change of impacts between meal groups and alternatives

The unexpected increase of WDP when changing from red meat-based meals to poultry-based meals is driven by the ingredients 'potatoes' and 'rice'. For both meals, Roast Chicken and Chicken Satay, only the protein ingredient is more significant by weight than 'potatoes' and 'rice' respectively. Across all ingredients in this study, the production of 'Rice' results in the second largest WDP value with 637 litres/kg and is therefore more than 4-times as impactful as 'Meat, from broiler' with 150 litres/kg. A similar relationship causes the high WDP value for the Roast Chicken meal, where 'potatoes' are twice as impactful as 'Broiler'.

While the average WDP value for the poultry-based meal group increases compared to the Red Meat-based meal group, the average CED is lower compared to the Red Meat-based meal group.

4.2.2.4 Meal composition

When removing potatoes as an ingredient from the only two meals that contain significant amounts of starch – Roast Chicken and Codfish - the impact results drop significantly by up to 74%. Codfish becomes the option with the lowest WDP value (Figure 4.14). This dynamic is particularly relevant when taking cost into account, which only decreases by 7.6 and 7.2% respectively for those meals when removing potatoes.

Rice has a similar effect on Chicken Satay. WDP contributions remain significant for meals that include salmon, because their land-based production system is highly water-intensive (4.1.3).

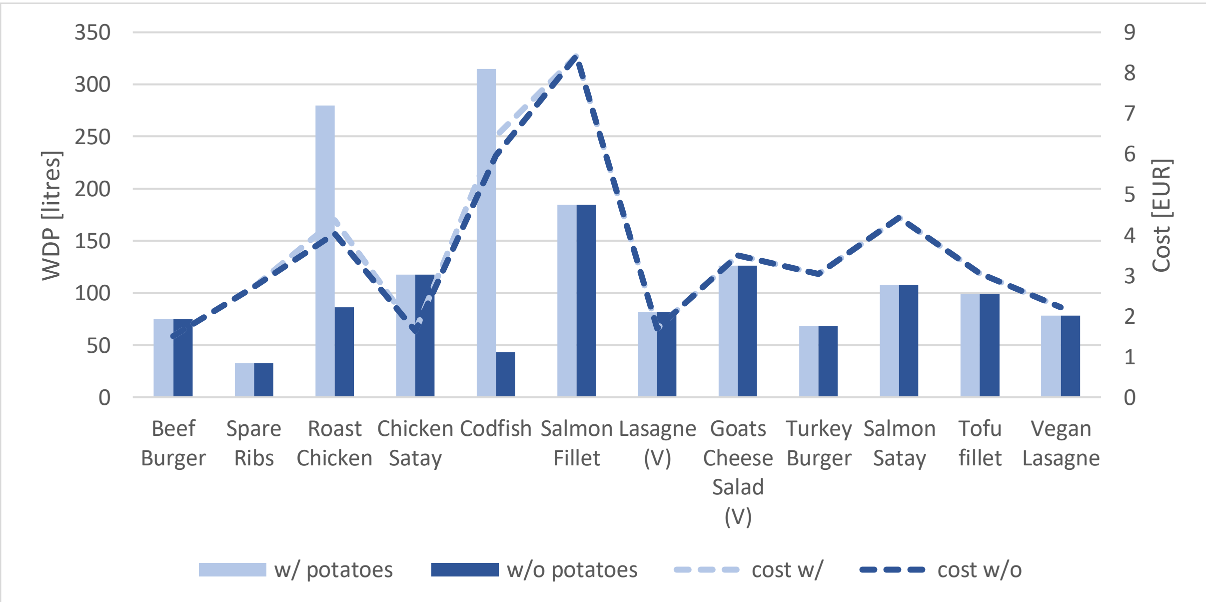

Figure 4.14 - WDP baseline results - potato adjustment

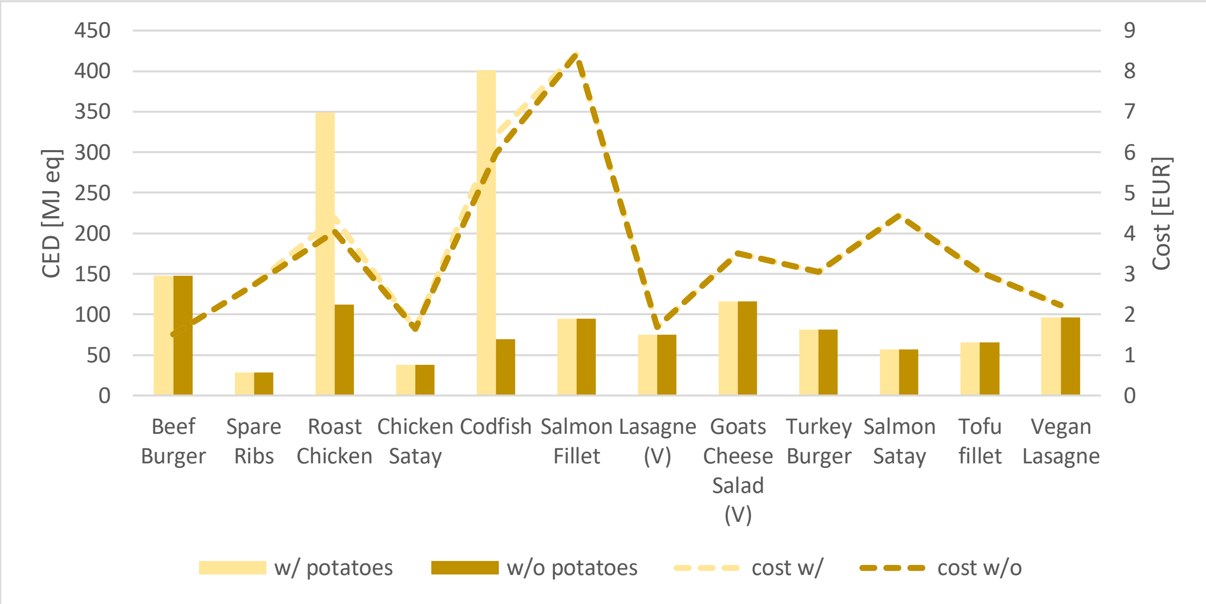

Figure 4.15 - CED baseline results - potato adjustment

4.2.2.5 Food storage duration

One of the most significant assumptions in the model is the auxiliary factor of storage duration. While the shelf-life of fresh ingredients are regularly limited to 3 days from the date of purchase, the model assumes a maximum possible storage for foods that are perishable within less than 6 months. Any foods that have a longer shelf-life are modelled without cooling during the 'Processing & Storage' stage. Figure 4.16 and Figure 4.17 illustrate that cooling contributes significantly to both impact indicators, where a reduction of the maximum possible storage duration by 90% results in impact reductions of between 8% (Chicken Satay, WDP) and 83% (Codfish, CED) as shown in tab 'Summary' (Claussner, 2019). However, reductions are more consistent within 26-60% for WDP and 47-77% for CED, indicating that cooling optimisation has the potential to significantly although not directly proportionally reduce the impact of meals across both indicators.

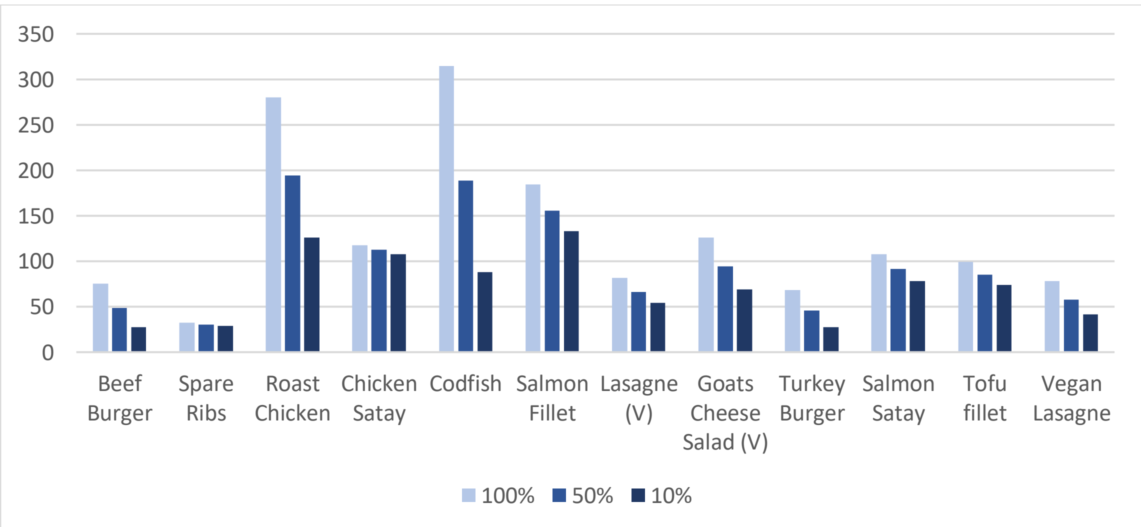

Figure 4.16 - WDP [litres] at fractions of maximum possible storage duration of perishable ingredients in the baseline scenario

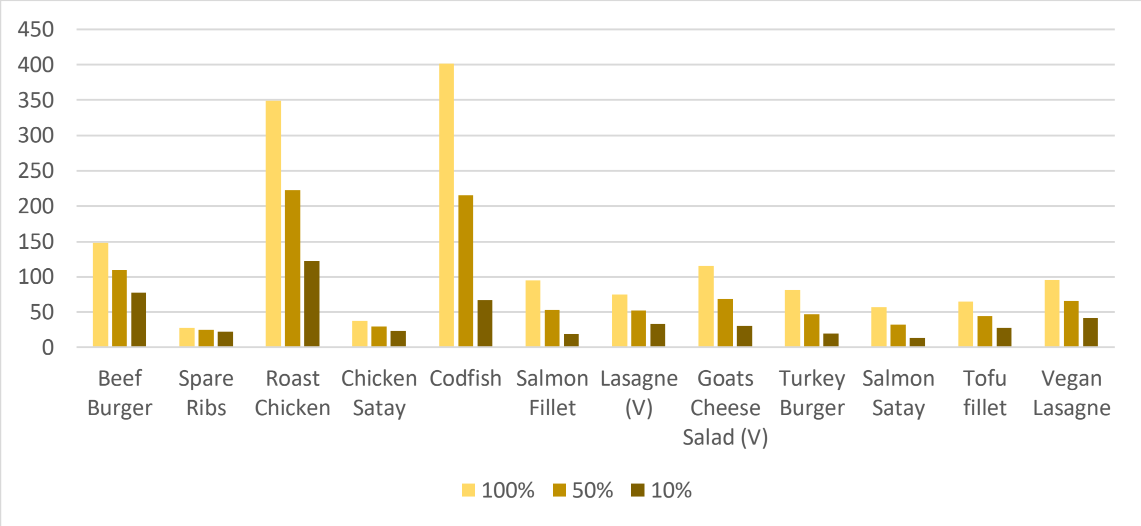

Figure 4.17 - CED [MJ eq] at fractions of maximum possible storage duration of perishable ingredients in the baseline scenario

4.2.3 Uncertainties

The selection of recipes for this study follows a subjective process, based on the author's extensive professional hospitality experience in the Netherlands and the UK. Similarly, Stichting DHLeo's selection of suitable dinner venues is based on subjective experience of Leiden's dining scene, which was shared with the author via email communications.

Although a simplified LCA approach is purposefully applied in this study (3.2.4.1), the significance and magnitude of skewed results because of replacing ingredients with proxy products already modelled in the background databases is unclear.

Another source of uncertainties are the parameters for auxiliary inputs that define the non-food items in the LCI. Agro- and hospitality-industry data from the UK and the US (Table 3.3) are aggregated for what is a highly fragmented and regionally distinct food system. Detailed data for specific processes (i.e. washing of fish, sizing of slaughterhouses, average wholesale storage duration of potatoes, etc.) is not available at the scale required to improve the data quality for this study. These conditions inherently incur an undeterminable and potentially significant level of error.

4.3 Summary of Results

The main findings of this comparative study are summarized below:

- the most popular meals on restaurant menus in Leiden are:
    - Beef Burger
    - Spare Ribs
    - Salmon Fillet
    - Chicken Satay
    - Roast Chicken
    - Codfish
    - Vegetarian Lasagne
    - Goats Cheese Salad

- Cumulative Energy Demand is a suitable indicator instead of GWP to communicate the magnitude of environmental impacts in this study
- In comparison between meals, the magnitude to Water Depletion Potential and Cumulative Energy Demand are sufficiently representative for most impact indicators in a full LCA, with the exception of indicators that are linked to diminishing water quality.
- The selected recipes indicate that Roast Chicken and Codfish result in the largest WDP and CED impacts
- When meals are adjusted to the same mass, the elasticity of impact results decreases, Salmon Satay yields the highest WDP impact and the CED impact of Beef Burgers is almost as high as Roast Chicken and Codfish
- Both scenarios that investigate organic production and background data from alternative sources result in increases of both indicators across all meals.
- Food cultivation and cooling during storage are consistently the most significant contributors along the supply chain
- For most meals, the results of both indicators are largely defined by no more than four ingredients
- Impact indicators seem to increase most for protein-rich foods from organic productions
- Substitution of meal groups with alternatives reduces WDP and CED impact results, except when substituting red meat-based meals for poultry-based meals.
- Individual ingredients such as potatoes can change the comparative results significantly
- The reduction of cooling requirements can reduce results for both impact indicators significantly

5 Discussion

In this chapter, the validity of the study's LCA results are assessed and their suitability for the intended application discussed. The robustness of the model is addressed along with the results' usefulness for the consumer. The final two sections explore how the findings can support decision-making of societal, managerial and policy stakeholder within the local context of this study and beyond.

5.1 Limitations

The study's methodology and modelling choices encounter several challenges.

5.1.1 Data availability and quality

Primary data from the restaurant survey are a snapshot in time and subject to constant change because of seasonal menu changes. Survey data is still useful and appropriate to identify variations of impacts across actual restaurant meal groups and individual meals. The survey data lacks quality in terms of ingredient specificity where mostly descriptors or item titles are displayed on menus. Variations in names across menus may refer to the same meal, but the applied methodology avoids interpretation and reliably identifies meals with the highest occurrences across all surveyed restaurants.

Recipes constitute primary data which is generally available and of high quality. The challenge is to collate a set of recipes that are appropriate for the local context and align in terms of quality (skill, time required) and quantity (macro-nutrient ratios, total weight, calories). Qualitative variations are addressed by selecting recipes that require basic ingredients, skills and tools as much as possible. Quantitative variations are addressed by normalizing the LCA results to a 500g portion size. Calorific normalization was not available within the scope of this study as not every recipe readily included this information. Normalizing for macro nutrients is expected to yield significantly different results for each nutrient type as highlighted in 4.2.1.1. However, as discussed in 2.3, investigations of such variations are largely inconclusive.

Production, processing and transport are modelled for each ingredient as those stages have the highest impacts along the supply chain (Notarnicola, Tassielli, Renzulli, Castellani, et al., 2017). In the baseline scenario, the production of 37 of 76 ingredients (48.7%) are modelled as 'global' or 'rest-of-world', which illustrates that almost half of the data in this study is aggregated to the highest possible level. Subsequently, processing and transport stages are also modelled with highly aggregated input data as detailed in tab 'OtherParameters' (Claussner, 2019).

5.1.2 Compatibility of tools and background datasets

5.1.2.1 Processing

This study is based on the use of two LCA tools (CMLCA and openLCA) that process two different background databases (EI and AB). The use of both databases in a single tool is possible but did not apply in this study due to licensing restrictions. The use of a single database for the simplified methodology in this study is not possible because several ingredients such as animal meats, fish, eggs and others were not available in the ecoinvent 3.4 background database. EI version 3.5 was not available due to licensing restrictions, but version 3.5 does include the production systems that are based on AB in this study.

5.1.2.2 Database alignment

While food LCA studies frequently use mixed resources (for example Filimonau et al., 2017b), there are issues surrounding insufficient alignment of LCA databases and reports in terms of methodology, data quality and compatibility (Cucurachi, Yang, Bergesen, Qin, & Suh, 2016; UNEP/SETAC Life Cycle Initiative, 2011).

The 'database' scenario illustrates that impacts for individual ingredients vary on average by 21.4% between EI and AB, while the average median of impact variations is only -0.3% as shown in tab 'ScenariosIngredientImpact' (Claussner, 2019). The dynamic in the 'organic' scenario is similar. However, these relationships are distorted by the fact that transport depends on a product's sourcing location, which the model does not automatically adjust for when the averages of the proxy ingredients are extrapolated to the whole dataset.

As a result, the impact variations between EI and AB can only be compared directly with ingredients where the transport system is modelled identically. These ingredients are carrot (NL, FR), maize starch (DE, FR) and tomatoes (NL, FR). The variations for WDP and CED between EI and AB range from -23.5 to 65.2% at an average of 17.8%. The largest average variation occurs for WDP at 31%.

This relationship is largely true for average variations across all ingredients, where WPD varies by 34.5% and CED varies by 8.2% (direct comparison 4.6%).

Where database discrepancies can be identified to be consistent, the model can be adjusted to accommodate these discrepancies. Based on the small and thus statistically unreliable sample set of comparative products in this study, an adjustment was not applied to the data.

5.1.2.3 Product data

Data can be submitted to EI by any person or organisation, but is subject to rigorous internal and peer assessment before publication.

AB is based on data from literature and statistical records as well as expert judgements, while most upstream and indirect flows were calculated using Simapro and the EI database according to AB's Data collection procedures and systems (Koch & Salou, 2016).

Both production system models rely on data that cannot be verified by the author within the scope of this study, but considering that AB is also based on EI background models, the discrepancies between the two databases can be interpreted as 'recipe variations' for the production systems they represent.

AB data can be considered more accurate for French production systems, but may not reliably represent other production systems compared to the aggregated dataset in EI.

5.1.2.4 Allocation

Allocation of impacts in multi-functional processes affects four background product systems in this study, all of which originate from AB. One of the four ingredients is Maize Starch which is only applied in the 'database' scenario and shows the lowest allocation rate of 75.8%. The four ingredients' average default allocation rate of 91.9% is significantly higher than a physical allocation would be at an average of 56.4%.

In CMLCA, secondary flows of multi-functional EI processes are modelled as waste and subsequently cut-off, so 100% of impacts are allocated to the products that are relevant to this study.

In AB, secondary flows do not occur for any processes other than Maize Starch and Meats from beef, broiler and pig. Hence, all other processes relevant to this study are subject to 100% allocation.

In effect, an allocation-related distortion of impact results in the four ingredients originating from AB is -8.1%. If found to be consistent, this value would reduce the discrepancies between the two databases as discussed in 5.1.2.2 by half.

As a result, the average compound effect of discrepancies in product system data and allocation method between EI and AB could be 7.7%. However, the comparisons between the two databases are based on narrow samples and do not achieve a level of statistical significance that would justify the application of this compound effect to the whole LCI dataset in this study.

5.1.3 Modelling choices and robustness

Beyond the selection of input data and modelling tools, several decisions along the modelling process affect the quality of the study.

5.1.3.1 Exclusions

In this study, the simplification and partiality of the LCA methodology refer to the assessment of a reduced number of impact categories for life-cycle stages up to consumption. Some of the aforementioned exclusions have been made in the methodology which affect the robustness of the results:

Restaurant fitout and operation

The installation and operation of a restaurant requires significant resources and can be the largest contributor to some impact category results (Baldwin et al., 2011). The author indicates that the operation of restaurants could almost double the average overall environmental impacts across a selection of 7 impact categories. However, procurement of food products is commonly the life-cycle stage causing the most significant overall environmental impacts, which is highlighted by Baldwin's normalized results and also assessed in this study. In addition, the consumer does not have any knowledge or choice regarding a restaurant's fitout, particularly concerning kitchens. While these are relevant aspects of a full-LCA study of individual meals, the scope of this study is limited to the comparison of impacts that are directly associated with the provision and preparation of the ingredients of served meals.

Packaging

The packaging of commercially supplied foods is based on various factors. Options range from unpacked fresh leafy produce to single-use wrapping made from a variety of materials, without any consistency for any ingredient. The constant development of packaging materials and technologies along with the variability of packaging type between different suppliers of the same product limit the representativeness of any packaging, if it was included in this study (Han et al., 2018). While menu items change regularly as well, ingredients may be purchased from a different supplier and therefore generate different types of packaging with every new order.

Seasonality of produce

Sourcing out-of-season food products is usually linked to longer supply routes and significantly different cultivation methods and technologies. Alternatively, in-season products can be frozen for out-of-season use. Both cases create an artifical supply of products at some point in time, which requires either transport, cooling or other additional resources such as packaging. However, out-of-season food supply may be advantageous when the resource requirements in a different local environment are favourable. Such is often the case with cultivation of produce in sourthern Europe and its consumption in central or northern Europe outside of the growing seasons. In this particular case and other global contexts, environmental burdens are often shifted to the production location where additional pressures such as water scarcity, urbanisation and biodiversity-loss may emerge. Generally, sourcing foods locally when in-season compared to regionally or globally when out-of-season results in little change in environmental impacts (DEFRA, 2012).

5.1.3.2 Impact categories

The two impact categories under investigation in the study are water depletion (WDP) and Total Cumulative Energy Demand (CED). Climate Change (GWP100) is initially highlighted because of its suitability in simplified food LCAs (Pernollet et al., 2017).

Figure 3.2 and Figure 4.2 show that CED and GWP100 follow almost identical trends across all meals. Tab 'BackgroundLCA' (Claussner, 2019) shows that the standard deviation of ratios between GWP100 and CED for EI background products is 3.8%, which indicates a strong correlation between the two datasets (Huijbregts et al., 2006). The two indicators are interchangeable when comparing the magnitudes of environmental impacts related to energy consumption and climate change. As climate change is a widely investigated and relevant impact category in food LCAs, the substitutability with CED highlights the relevance and validity of the results from this study.

When comparing the WDP values of background products across both databases with comparable products' grey and blue Water Footprints (M. M. Mekonnen & Hoekstra, 2011b; M M Mekonnen & Hoekstra, 2010), the standard deviation is over 3m%. The Water Footprint method includes green water, which "is water from precipitation that is stored in the root zone of the soil and evaporated, transpired or incorporated by plants. It is particularly relevant for agricultural, horticultural and forestry products" (Water Footprint Network, n.d.-b). Despite its relevance for agricultural products, green water is excluded from the comparison to match the ReCiPe methodology where water abstracted from lakes, rivers, well (in ground) or unspecified natural origin is accounted for. Fresh water from precipitation cannot be actively abstracted and is therefore not a referable resource in this context.

Excluding the three highest discrepancies (AB - faba beans, EI - soy beans, EI – fava beans) out of a total of 54 compared products reduces the standard deviation to 717%, meaning that the average discrepancy between a product's WDP and Water Footprint values in the LCA model varies by a factor of 7. This indicates a poor correlation between the two datasets.

Water Footprint values are estimated from aggregated datasets (Hoekstra, Chapagain, Aldaya, & Mekonnen, 2011, p. 28) and usually do not match the level of detail of data that is submitted to and published by LCA databases such as EI (Weidema et al., 2013, p. 30). The granularity of Water

Footprints at the level of nations and only occasionally for national regions illustrates the aggregated nature of the data.

5.1.3.3 Scenarios

In each scenario, the impact scores of all ingredients are adjusted based on the average values across the proxy ingredients. While this method is applied to achieve consistency across the scenarios, it includes a level of error that varies between each scenario because of the different number of proxy ingredients in each case.

The marginal changes in the 'organic' scenario can reflect inadequate differentiation in the background databases, which has been shown to be frequently the case (Meier et al., 2015).

5.1.3.4 Meal categories and their alternatives

Each category is made up of two popular meals that were identified by the restaurant survey. As such, the categories are representative for Leiden dinner menus only. The results of the LCA study indicate that the Red Meat-based meal category achieves the lowest WDP and CED impacts. However, as highlighted in 4.2.1.1, the composition for all meals in this study varies. This is most significantly the case for both meals in the Red Meat-based meal category, where neither meal include any starch. This is particularly relevant as ingredients such as potatoes contribute significantly to impacts in meals such as Roast Chicken (4.1.3). Further, Spare Ribs do not contain any significant amounts of vegetables either, while 'lettuce' contributes between 21.5% (CED) and 32.2% (WDP) to the impacts in the Beef Burger. As a result, Spare Ribs achieve the lowest impact scores in this study, while potatoes contribute between 68% and 86% to impacts in Roast Chicken and Codfish respectively in the baseline scenario.

When the two most significant starch ingredients - potatoes and rice - are omitted from the model, the highest contributions to environmental impacts across all meals shift towards the following ingredients:

- Animal-based products (meat, dairy)
- Exotic ingredients (coconut, citrus fruit)
- Vegetables with long shelf-life (onion)
- Ultra-low density vegetables (spinach, lettuce, leaves)

Most menu items in the survey and therefore most meals in this study are nutritionally incomplete, so it is considered to be likely that diners would complement their choice with side dishes. As shown above, this circumstance significantly affects the impacts associated with the entire meal.

RQ 3 - The simplified LCA results are representative for the meals and their composition, but are mostly subject to uncertainties about background data in the model, rather than the methodology of the model itself. Uncertainties within the data have the largest effect on individual ingredients. Within and across meals, the impact results reflect recipe and supply changes.

5.2 Usefulness for the consumer

The LCA study provides scientific understanding of relationships and hotspots of environmental impacts across menu options and within individual meals. As such, the work contributes to a body of research and particularly provides insight for the Leiden restaurant environment. However, research findings can only affect changes in the food system if they are usefully communicated to various stakeholder groups, of which consumers are frequently cited as the most relevant and influential (1.3, 2.1). The following sections discuss whether the results' quality (type of indicator), magnitude (values) and perception are useful to the consumer, and what kind of secondary effects on society could be triggered by implementing result-based changes in the food system.

5.2.1 Understanding impact indicators

The impact indicators in this study reflect the dimensions of the Nexus and are therefore address some of the most pressing environmental issues in the context of food as well as other industries.

The default unit of WDP is cubic meters, which is a volumetric measure that most people understand, especially when converted to litres. Consumers are most frequently exposed litres when purchasing beverages, dealing with utility bills or through environmental awareness campaigns for other consumer goods. For example, a common size for beer is 0.5l, daily domestic water consumption in the Netherlands was 149l per day in 2014 (eurostat, 2017) and the production of one t-shirt takes approximately 2500-2700l (Drew & Yehounme, 2017; Water Footprint Network, n.d.-a).

The default unit for CED is mega joules (MJ), which expresses energy. While MJ as an energy unit may be less familiar to the general population, it can be conveniently translated into other units such as kW, kWh, mAh (depending on context), which are frequently mentioned in electronics specifications, battery capacities and utility bills.

5.2.2 Interpretation of results

As such, the impact indicators under investigation in this study can be expressed in a variety of units that the consumer can relate to from personal experience in a physical environment. Examples could be smart-phone battery life [hours] or average EV range [km] for CED and average shower [minutes] or pints of beer [#] for WDP. Such comparisons must clearly correlate to the magnitude of the experience rather than the environmental impacts that is associated with the provision of the product behind the experience.

Nutrition labels of store-bought foods currently contain a measure of energy content which is expressed in calories (kcal) and kilojoules (kJ). As the CED values in this study relate to embodied energy, a clear distinction between the two metrics is needed to avoid confusion, even when they are not displayed together.

Putting the results into a familiar context can make the information more relatable. In this study, ingredient prices can also serve as context for lack of reliable data about taste or health aspects (Hoek, Pearson, James, Lawrence, & Friel, 2017). Normalized results can be combined into composite values to avoid discrimination of either Nexus dimension. When they are expressed in terms of ingredient cost as a composite ratio (i.e. m^3*MJ / €), a low value could indicate a more appropriate price for the magnitude of environmental impact caused by a meal. A high value would indicate that the ingredient costs are inappropriately low compared to the environmental impact per Euro spent. While this can be useful to express impact results in terms of economic value, low composite ratios do not automatically infer lower environmental impacts. Also, definitions for 'appropriately priced' and 'inappropriately low priced' would have to be defined and benchmarked. Further, low composite ratios do not directly affect more sustainable practices along the supply chain.

However, the production system could only effectively compete on resource efficiency in order to reduce composite ratios as an increase in ingredient cost is limited by the consumer's willingness and capacity to cover higher costs, and the restaurant's profit margin.

The composite ratio as a metric implies the risk of a rebound effect (Herring & Roy, 2007). As a result of spending more money on a meal with a low composite ratio, consumers may subsequently opt for cheaper and more impactful products or services.

A different combination of WDP and CED values can indicate the freshness of products, as it is the case with most ingredients in this study that require cooling but have a long shelf-life. While seasonality has not been investigated in this study, out of season food products either require long-term refrigeration or long-distance transport. In both cases, such ingredients contribute significantly to the overall impact of meals. Examples from this study are potatoes with a refrigerated shelf-life of 3 months and carrots with a 28% increase in energy demand due to long-distance supply. High CED contributions during the processing stage of the supply system can be avoided by opting for seasonal and local food products.

While this study has addressed whole meals, the underlying results refer to individual ingredients. This information can be disseminated further to inform the consumer and raise the awareness for comparative impacts from food items.

5.2.3 Behavioural economics

Format and context of environmental impact information and communication are relatively insignificant for behavioural changes in consumers (Hoek et al., 2017). This challenge is compounded by the fact that Dutch consumers suffer from optimism bias in terms of percieved sustainability of foods such as meat (Geurts et al., 2017). In this context, factual information such as impact results from LCA studies may be preferrable to label-systems, which are currently perceived as confusing instead of supporting dietary adjustments. Interpretation of current labels requires pre-existing knowledge as the Millieucentraal's website illustrates (milieu centraal, 2019). Familiarity with the concepts of labels do not equate to detailed knowledge of their meaning. What exactly does fairtrade stand for? What does Demeter specify?

Environmental labels can be effective across western cultures and have the potential to be readily accepted by up to 40% of the population (Peschel, Grebitus, Steiner, & Veeman, 2016). However, they may not be an effective intervention to promote a certain type of diet or consumption behaviour when numerical values are not meaningful or confusing (van Amstel, Driessen, & Glasbergen, 2008). Specifically organic and local food is desirable to consumers, but a general sense of powerlessness and alienation from the decision-making process does not position the consumer well enough to drive sustainability in the food industry (Garnett, Mathewson, Angelides, & Borthwick, 2015). In addition, consumers increasingly question the benefit of organic production per se. Achieving a significant reduction of environmental impacts in the food system based on self-regulatory interventions seems unlikely, which reinforces the need for a more overriding criteria that can indicate sustainability of foods (Vittersø & Tangeland, 2015).

"Voluntary actions appear to be recognized by organized and informed consumers and create a virtuous cycle for retailers". A coordinated labelling effort to promote organic and local foods can be seen as a driver for broader sustainability investment (Claro, Laban Neto, & de Oliveira Claro, 2013). There are currently many voluntary programs across the EU retail landscape with many of them not including clear quantitative information which makes comparison more difficult across labelling schemes, businesses and typologies (Chkanikova & Mont, 2011). Sustainability labels of foods in particular are currently not relevant for consumers' food choices and their effectiveness is largely subject to pre-existing environmental concern and knowledge by the consumer (Grunert, Hieke, & Wills, 2014). Further, quantity or quality of sustainability information alone has hardly any bearing on consumer behaviour, but connecting information to existing decision-making processes is more likely to achieve the desired outcome, especially when associating sustainability factors to health benefits (Hoek et al., 2017; O'Rourke & Ringer, 2016).

Labels have also been proven to be more effective when primary data is supported by contextual or interpretive information (Sinclair, Cooper, & Mansfield, 2014), or numeric values are communicated through colour codification (Ellison, Lusk, & Davis, 2014; Filimonau et al., 2017b). However, a coherent and consequently applied labelling policy is needed to change the food system through voluntary declarations. Otherwise there is a risk of selective labelling to avoid disaffecting certain products (Gadema & Oglethorpe, 2011). Labelling can be considered a form of 'nudging', where the goals is the avoidance of bad decisions or mistakes. Grounded in the field of behavioural economics, this tactic can be successfully applied to introduce new policy or expand existing interventions. However, if implemented without caution, 'nudging' can become an expression of paternalistic policies where consumer choices are curtailed (Lusk, 2018).

Clearly linking economic value to environmental performance and simlifying the purpose of a label can achieve a shift in perception of both relevance of labels and impacts related to products. While financial instruments can be effective, it should not be the primary objective of the any environmentally-driven intervention to reduce but consequently shift consumer spending towards less impactful products. The aforementioned rebound effect should be avoided.

5.2.4 Social implications

As this study does not address nutritional value of meals, the results are unlikely to directly support a healthy diet. However, there are a number of positive effects a diet change according to this study's LCA results can have.

Sourcing foods locally and according to the seasons can significantly reduce environmental burdens globally. This sourcing strategy can contribute to local direct and indirect employment opportunities. A technologically advanced agricultural industry such as in the Netherlands can benefit from such a strategy by exporting local expertise rather than physical products. In such a win-win scenario, local food systems around the world can become more self-sufficient while resources are preserved.

On the other hand, less technically advanced economies would suffer from decreasing global food trade, which is the single most relevant economic sector in some countries that produce exotic foods. A prominent example is Ethiopia where 68% of the workforce is employed in agriculture and the country's top export product - coffee - accounts for 2.9% of global coffee exports (Central Intelligence Agency, 2018; The World Bank, 2018).

Food diversity would likely decline in a localized food system as plant species depend on specific climate and soil conditions that cannot always artificially replicated.

5.3 Relevance for managerial and policy stakeholders

5.3.1 Business management

Sustainability indicators often refer to the whole operation of restaurants (Legrand, Sloan, Simons-Kaufmann, & Fleischer, 2010), rather than the assessment of individual product options over which the consumer has more decision-making power (Jacobs & Klosse, 2016).

Additionally, environmental credentials alone do not intrinsically translate to additional revenue because of high elasticity of demand. However, communicating environmental performance can build trust, reputation, and expand the customer base. While people are generally not aware of environmental efforts in hospitality businesses, they tend to be willing to pay extra fees when made aware (Sarmiento & El Hanandeh, 2018).

Organic menu items can support consumer decisions to select a particular venue, but this does not seem relevant in casual and upscale dining and indeed does not influence intentions and attitudes of patrons (Lu & Gursoy, 2017). This confirms the trend that organic products are subject to the same level of perceived benefits or risks associated with conventional products (Vittersø & Tangeland, 2015). As shown in section 4.2.2.4Error! Reference source not found., ingredient costs and impacts correlate in this study and organic production has no significant environmental benefit compared to conventional production. It therefore seems that businesses always benefit from purchasing cheaper products, especially when they're produced locally and are within season.

When restaurants communicate impact values of menu items directly to consumers, they are likely to be held accountable regardless of the fact that the largest the largest contributions occur further upstream along the supply stream during the production, transport and processing stages. This dynamic should encourage businesses to engage more with suppliers and producers to reduce impacts at various levels in the food system, rather than focussing too much on improvements within their own business that have negligible effects on the product as a whole. An example of such initiatives that are limited in scope is the Green Key certification programme (Green Key, 2014). As discussed earlier in this study, such labels may be generally recognized by consumers, but there is limited understanding of their meaning without pre-existing knowledge and behavioural changes are highly unlikely.

At the time of this study, environmental information is generally not displayed on restaurant menus. While the display of rudimentary and relatable metrics that help 'nudging' patrons towards more sustainable meal options (Filimonau et al., 2017a), the effectiveness of such a strategy may be rooted in the novelty of the concept. Restaurant managers can also employ 'nudging' as a sales tactic and instruct staff to recommend low-impact dishes (and side dishes) as a default. The consumer's options are not reduced, but they would effectively have to opt-out of the environmentally preferable option (Pichert & Katsikopoulos, 2008).

While the results of the LCA study support the claim that local seasonal food causes lower environmental impacts, the sourcing of such products should still follow an optimised industrial approach. Otherwise, benefits are easily off-set by fragmented supply strategies (Coley, Howard, & Winter, 2009), which also indicates a high elasticity of environmental impacts across systemic interventions in the food system.

Based on the high variability of contributions from individual products such as potatoes, businesses may choose to redesign meals so that such ingredients are offered as a side dish and thereby facilitating a more accurate presentation of the environmental impacts of individual items. Such a strategy, however, could lead to a profit decrease because margins on cheap staple items such as potatoes are much higher than expensive low-impact ingredients. On the other hand, this type of menu design can. In this scenario, the consumer can decide more confidently about the impact of their whole order. Tapas are such a meal type, where small dishes frequently contain only few ingredients and the consumer combines these to compose a whole meal.

Low cost items can have large water and energy impacts, as displayed by potatoes in this study. This is a challenge for businesses, because there is a larger profit margin on low-cost foods, and communicating potentially high impact scores to consumers could making them less desirable and therefore affecting the profitability of the business. Technical innovation in the production local production system could address this hotspot for in-season produce while overseas supply may represent a favourable alternative outside of the growing season.

The environmental impact results from this study are directly useful to illustrate and communicate the implications of ingredient and meal choices in restaurants. The results can be easily converted into metrics that are generally familiar and meaningful. The results also directly reflect the large impact contributions that specifically occur during the processing stages without the need to disseminate the data.

5.3.2 Municipal policy

This study provides compelling arguments for policy-makers to require food businesses to collaborate closer with stakeholder along the supply chain with the goal of reducing water and energy use within the whole food system. The implementation of such a policy on a local level such as the Gemeente Leiden can provide a more agile environment for the development of strategies, metrics and relevant markets. Current policy agendas largely revolve around food waste reduction and qualitative targets (Lucas, Ludwig, Kok, & Kruitwage, 2016), while there is a lack of quantitative goals and suitable, harmonized and aligned metrics and indices (Melhart, Reijs, & Raster, 2016). Quantitative interventions on a local level are more adaptable and can be more effective in making local food systems more attractive and accessible.

The LCA results in this study generally support this approach, although the level of aggregation of background data and subsequent uncertainties makes the results more robust in a national or regional context. As such, the application of findings in policies or regulations within a small to medium sized municipality can serve as a case study. Small-scale pilots are useful to test data systems, metrics and benchmarks which will be essential on a national and regional level to deliver meaningful impact reductions. While some of the data that is relevant to the impact indicators in this study already exists within businesses' balance sheets (i.e. water consumption, energy consumption, production volumes), other elements such as data exchange interfaces and data protection methods may need to be developed.

Some of the areas, which were identified in this study and should be addressed by systemic interventions are:

- In-time supply of products to reduce storage duration and spoil
- High-efficiency cooling and storage facilities

- Mandate pro-environmental options as default to guide consumer behaviour. This should relate to either economic value or health benefits, but needs to be implemented with caution to avoid moral issues, paternalistic manipulation and financial disadvantages (Lehner, Mont, & Heiskanen, 2016; Pichert & Katsikopoulos, 2008)
- Frequently published WDP and CED data for most food products, frequently reviewed benchmarks for appropriate WDP and CED values per product unit
- Empower consumers to become 'carbon-capable' through campaigns and education (Whitmarsh, Seyfang, & O'Neill, 2011)

Policy intervention must address individual and structural barriers, they must be devised systemically and include all stakeholder groups within the food system.

Implement a levy similar to carbon on water depletion – this would bypass the consumer having to make an active choice, but when businesses pass on this levy, demand will automatically decrease because certain foods will become unaffordable for the consumer – this should only apply to food outlets rather than retailers, in order to manage high-impact foods – this only addresses the production issues and not all impacts up to the point of consumption. However, a water depletion levy could be applied at all abstraction points.

5.4 Scalability

5.4.1 Spatial scalability

With minor modifications to some auxiliary data such as transport distances, the model can be applied to different environments of various size within the Netherlands and other western European economies. The EI database is continuously developing new product systems at increasing granularity, especially within Europe, which can support a more detailed differentiation of this model's results from different locations.

When the model is applied to a larger spatial boundary, local food options cannot be easily represented or require a much more differentiated analysis. At the same time, the background data used in this study will become more appropriate as the level of granularity is only occasionally available for nations and mostly for regions.

5.4.2 Sectoral scalability

The application of this model to different industries or sectors is possible when the resource demands or known environmental burdens of a given product or service directly correspond to the Nexus dimension. As such, sectors that derive most of their productivity from fossil or agricultural resources can use this model. The fashion industry is such a case where mainly agricultural and fossil resources are processed at the cost of water pollution and greenhouse gas emissions (Drew & Yehounme, 2017). The impact indicators can be expanded to include land-use, which is another emerging Nexus dimension that the general population can easily relate to. However, further methodological development of the LCA method may be needed to achieve robust results from simplified studies (Karabulut et al., 2017).

The results of this study highlight the contribution of environmental impacts along the supply chain of the food system in the Netherlands and the opportunity to distribute the responsibility for reducing those impacts among various stakeholders. The findings align well with existing policy goals and business intentions, supporting a simplistic mechanism to quantify impacts on a more granular level within local and short supply systems

6 Conclusion and recommendations

This chapter reviews the study's results against its goals, summarizes how the methodology enabled the research and how the main findings have contributed to answering the research questions. Finally, opportunities to expand on this study are explored.

6.1 Recap of study goal

The literature review revealed that food sustainability policy agendas increasingly incorporate the Water-Energy-Food Nexus as an approach to mitigate environmental impacts along the food supply chain. Scientific accounting methods are frequently referenced as the preferred analysis method to gain insight into possible pathways for the reduction of water and energy use in relation to food production, distribution and consumption. A research gap was identified where the results of academic research are comprehensive and useful to various stakeholders. The information would enable policy-makers, businesses and consumers to effectively implement measures to reduce environmental impacts across all three Nexus-dimensions.

The study set out to investigate the robustness of a simplified LCA method and the usefulness of its results with the aim of contributing new insight to the research gap.

6.2 How the study was carried out

The study was supported by the Stichting Duurzam Uiteten in Leiden en omstreken, who contributed to the initial phase of surveying the menus of Leiden's dining establishments based on the organisations local knowledge. This bottom-up approach of generating primary data was complimented by the top-down application of aggregated data in the subsequent LCA of a range of meals. The results of the LCA and its underlying data model were examined against relevant external resources and for internal robustness. Findings were then discussed in the context of stakeholder interests, drivers and potential mechanisms that would utilize the study's results to mitigate upstream water and energy consumption of restaurant meals.

6.3 Main findings and limitations

When comparing upstream water and energy consumption of meals served in restaurants, the simplified LCA study showed that individual ingredients and the storage duration of perishable foods can significantly affect the results. Long-distance supply and organic production generally increase the water and energy demand of meals. The methodology of this study was found to be robust, but not without uncertainties regarding the compatibility of analysis tools and background data. The results imply extensive extrapolations based on a relatively small number of reference calculations, which represents the most relevant source of error in this model. However, due to limited availability of more appropriate data within the simplified methodology, this was deemed acceptable.

The water and energy consumption results were found to be applicable in various ways for all stakeholder groups, ranging from menu labelling to creating less impactful recipes and financial incentives by regulators to stimulate local and seasonal supply.

6.4 Answers to the research questions

Following the identification of the research gap, the main research question of 'How can simplified LCAs of restaurant meals in a medium-sized city in the Netherlands effectively support decisions to reduce the environmental impact of the food system?' was formulated and supported by a number of sub-questions. These were successively answered along as the study progressed and summarized below.

Q1 – What are the comparative upstream energy and water demands of these dishes at the point of consumption?

The impact results are listed in Table 4.1. Roast Chicken and Codfish show the highest values for water depletion potential and cumulative energy demand. Spare Ribs and Turkey Burger show the lowest values for water depletion potential while Spare Ribs and Vegan Lasagne requires the least amount of energy.

Q2 – How reliable are the results of a simplified LCA method for these indicators?

The results represent the impacts associated with the specific recipes and valid modelling assumptions along the supply chain. There is some uncertainty about the compatibility of analysis tools and background databases which affects the magnitude rather than the quality of patterns. The model significantly relies on extrapolation from a small number of reference results, which is an acknowledged potential source of error that cannot be further examined within the scope of this study and available data.

Q3 – How can the results support decision-making of other stakeholders in the food system in the context of Leiden and other Dutch cities?

The results of this study highlight the contribution of environmental impacts along the supply chain of the food system in the Netherlands and the opportunity to distribute the responsibility for reducing those impacts among various stakeholders. The findings align well with existing policy goals and potential business intentions, supporting a simplistic mechanism to quantify impacts on a more granular level within local and short supply systems.

6.5 How can research expand upon this study

This study adds insight to the broader literature about food sustainability in several ways. The results indicate that mixed background databases can be used for this type of simplified, partial LCA methodology and provide valid insight. In effect, the study shows that non-commercial tools and resources can be used by non-scientific users to gain insight into the water depletion and energy demand composition of restaurant meals. This is particularly useful where restaurant owners/operators seek to understand the environmental impacts of their menu in a Nexus context.

The applied methodology was mainly carried out in Microsoft Excel and forms the foundation to develop a more user-friendly tool that can provide location-specific results.

The following recommendations emerged over the course of this study and are intended to improve the robustness and applicability of the methods and their results:

- The normalization in this study intended to simulate the inclusion of a side dish that would complement a meal and align better with a recommended balance of macro-nutrients. As such, the methodology could be extended to either include typical or most popular side dishes within the same survey boundary. Alternatively, to represent the dining patterns more accurately, a survey could capture customer orders.

- A simplification of the method could make the application of the model convenient for individual businesses. As a result, environmental impact mitigation could become a competitive advantage for restaurant owners
- Few academic studies currently investigate environmental and nutritional aspects of food in the context of sustainability. It is proposed that the model could be adjusted according to the content of macro-nutrients in individual ingredients or dishes. As a results, the model could elevate awareness of environmental impacts to the same level as dietary awareness among the public. Such results are also expected to be integrated more easily into existing dietary guidelines
- Both background databases provided data of production systems that were aggregated to national, regional or global level. Location-specific cultivation data would make the results more relevant to a local audience
- As WDP does not address water pollution as highlighted by the full LCA results, various indicators could be consolidated into a more inclusive metric to reflect any alteration of natural water resources.
- As the decarbonisation of the energy system progresses, CED will become less representative of greenhouse gas emissions but other challenges around rare earth metals in renewable energy technologies will need to be captured. The shift of environmental impacts towards other materials and substances could be addresses with a compound metric.
- As Nexus research and policy initiatives increasingly include land-use as an additional metric, it is recommended to explore the feasibility and usefulness of communicating a third metric to supply chain and policy stakeholders. It is anticipated that the complexity of four dimensions (Water-Energy-Food-Land Use) would face significant barriers in communication and dissemination of information for the benefit of mitigating environmental impacts
- The method could be tested in another low-involvement consumer-market that generates significant environmental impacts within the Nexus dimensions such as fashion to assess its potential for scalability. The fashion industry is an equally global product system although database resources are anticipated to provide even less detailed data, which presents a significant challenge in making such a study reliable and useful

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8 Appendix

- Excel-file '19 04 03 ThesisCalcs.xlsx'
- CMLCA-file 'ecoinvent34_v1.1.lca'
- openLCA zip-folder 'Agribalyse 1.3'