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Carbon footprint of diets of Norwegian households - status and potential reductions

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I dedicate my thesis to my parents Marie-Gabrielle and Christian Stamm.

Their steady support accompanied every choice I made along my education pathway and during any moment of doubt.

Abstract

English

The present work aims at quantifying the current carbon footprint of diets of average Norwegian households with a holistic perspective, and assessing various ways to reduce it. The scope of the research comprises food consumed and food-related activities happening at home, including food transport, storage and preparation.

After an introduction of the context of the research, its research question, goal and scope, the report reviews existing literature. It then presents the methods used for its own analysis, and its results. The analysis is then discussed, and the work concludes with a brief review of its main findings and challenges.

Two models were built separately. One assesses the carbon footprint of food consumption as well as food waste, and the other makes the same assessment for food supply. Both models served to calculate their associate system's current carbon footprint, and to build scenarios to assess reduction potentials.

The analysis finds higher emissions embodied in food consumption than in food waste and in food supply. An average Norwegian has a diet carrying emissions of 1233 kg CO_2-e per year, to which wasted food adds embodied emissions of 114 kg CO_2-e per year, and for which food transport, storage and preparation at home carry emissions of 203 kg CO_2-e per year.

Main limitations of this analysis comes from uncertainties lying in the data.

The present work calls for further research to lower the uncertainty level, and to assess the system's footprint on other impact categories.

Preface

This master thesis is carried out as part of the Industrial Ecology master program, Department of Energy and Process Engineering, Norwegian University of Science and Technology. It models and analyzes carbon footprint of the specified system, using methods previously taught as well as independently developed.

The thesis was carried out under the supervision of Professor Edgar Hertwich and co-supervision of Doctor Kjartan Steen-Olsen from the Industrial Ecology program at NTNU. The goal and research question were decided in collaboration with Trondheim-based startup Ducky, which will use the results presented at its own ends.

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List of abbreviations

CO_2-e: CO_2 equivalent

EU: European Union

FU: Functional Unit

GDP: Gross Domestic Product

GHG: Greenhouse Gas

GHGE: Greenhouse Gas Emission

GWP: Global Warming Potential

IOA: Input-Output Analysis

LCA: Life-Cycle Assessment

LCI: Life-Cycle Inventory

w/: with

w/o: without

WHO: World Health Organization

1. Introduction

1.1 Background

According to the latest Intergovernmental Panel on Climate Change (IPCC) report, “warming of the climate system is unequivocal, as is now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level” (Alley et al., 2007). Whether or not this climate change has a natural cause is a continual debate, but international experts agree to say that anthropogenic activities are “very likely” to explain its evolution since the industrial era (Alley et al., 2007). Greenhouse gases, responsible for global warming, are defined as those that “effectively absorb infrared radiation, emitted by the Earth’s surface, by the atmosphere itself due to the same gases, and by clouds”(Baede, Report, Use, Change, & Earth, 1986). The principal gas affecting the Earth’s radiative balance is carbon dioxide (CO_2), principally caused by the burning of fossil fuels and land use change (Baede et al., 1986). Agriculture is the main cause of the increased emissions of the other main GHGs: methane (CH_4) and nitrous oxide (N_2O). Governments around the world have acknowledged the importance of mitigating climate change; international summits are held regularly with the aim of limiting emissions that arise from production activities.

Hertwich and Peters (Hertwich & Peters, 2009) analyzed GHG emissions (GHGE) associated with the final consumption of goods and services on a global level. According to their analysis, 72% of global greenhouse gas emissions are due to household consumption. Additionally, the same authors found that out of 8 consumption categories, food consumption is responsible for 20% of the global GHGE. They also prove that food is the most important consumption category in terms of non-CO_2 GHGE due to households’ demand.

In terms of environmental policy, Norway is one of the world’s pioneers and is a key influence for European Union (EU) environmental policies according to the Organization for Economic Cooperation and Development (OECD 2011). In some areas, Norway has adopted environmental requirements more stringent than those set by the EU.

Despite Norway's leadership position, GHGE continue to increase and environmental problems regarding agricultural landscapes and waste generation remain of concern. Further improvements of Norway's environmental performance is thus not only but also desirable. Transparency and accountability are one of the keys to efficient policies. It is thus of importance for Norway to estimate its footprints in all domains and take it as a base for improvements.

Providing an assessment of the carbon equivalent emissions of Norwegian food consumption is relevant for the reasons mentioned above: the high responsibility share of households in terms of GHGE, the high contribution of food consumption, and the desirable reduction of Norwegian GHGE. The term 'carbon footprint' will be used to designate the CO_2-e emissions arising along the life cycle stages of a product or an activity.

1.2. Research question, goal and scope

The goal of the thesis is to quantify the current carbon footprint of diets of average Norwegian households with a holistic perspective, and to assess various ways to reduce it. The research question to be answered is: What is the average carbon footprint of Norwegian diets and how can it be reduced?

Analysis of carbon footprints associated with food consumption and household related activities fall into the scope of the thesis. This includes carbon footprint assessments of the current average food consumption for various population groups, food wastes, home food transportation, storage and preparation. Food consumed outside the home (i.e. restaurants, cantinas, hotels) falls outside the scope of this investigation.

1.3. Thesis outline

The first chapter will review the main existing literature relevant to the thesis.

The second chapter presents the methods used for the analysis. The chapter aims at giving the reader an understanding of the methodological basis to the results.

The third chapter introduces the results for the current situation in Norway in all domains analyzed, as well as the quantification of reduction potential scenarios.

The fourth chapter provides a general discussion on the work done. The section gives the reader a perspective on the analysis both in terms of uncertainties that need to be considered, and in terms of implications of the results that can be drawn from the analysis.

The fifth and final chapter concludes the work by briefly reviewing the main results and issues discussed.

2. Literature Review

Household consumption is responsible for a significant share of GHGEs, and the role of food consumption in a household's footprint is significant (Jones & Kammen, 2011). Therefore, environmental impacts of food consumption is a relevant topic for the mitigation of climate change and researchers have looked at the question with different approaches and from different angles that will be presented hereafter.

2.1 Assessments of food consumption carbon footprint

2.1.1 Main approaches

A large part of life cycle inventories (LCI) and life-cycle analyses (LCA) exist for all types of food products (Carlsson-Kanyama, Ekström, & Shanahan, 2003; Carlsson-Kanyama & González, 2009; Carlsson-Kanyama, 1998; González, Frostell, & Carlsson-Kanyama, 2011; Wallén, Brandt, & Wennersten, 2004). These findings on food products impacts were often associated with the conduction of impact assessments of specific meals (Carlsson-Kanyama & González, 2009; Davis, Sonesson, Baumgartner, & Nemecek, 2010; Virtanen et al., 2011) and diets (Baroni, Cenci, Tettamanti, & Berati, 2007; Gussow, 1995; Pimentel, 2003; Stehfest et al., 2009; Tukker et al., 2011; White, 2000). In addition to assessing the environmental burdens of a given consumption pattern, some studies also assessed reduction potentials of food consumption impacts (Reijnders & Soret, 2003; Stehfest et al., 2009; Tukker et al., 2011).

The concept of "food miles" as a measure of distance that food "travels between its production and the final consumer" (Weber & Matthews, 2008) received media and public attention in the USA and the UK. Scientists seek to scientifically test the concept (Coley, Howard, & Winter, 2009; Edwards-Jones et al., 2008; Weber & Matthews, 2008).

Research has also been conducted to compare carbon intensities with nutrient intensities (Carlsson-Kanyama et al., 2003; Davis et al., 2010; Drewnowski et al., 2015; González et al., 2011; Reijnders & Soret, 2003; Tukker et al., 2011; Virtanen et al., 2011; Wallén et al., 2004), raising attention on the positive correlation between health and sustainability.

In later years, studies have mostly focused on diet analyses. Recent reviews assess the current available literature on dietary scenarios (Hallström, Carlsson-Kanyama, & Börjesson, 2015), dietary impacts (Heller, Keoleian, & Willett, 2013) and the sustainability of dietary recommendations (Reynolds, David Buckley, Weinstein, & Boland, 2014). Green et al. (2015) added to their review an assessment of emissions reduction potential of a diet following World Health Organization (WHO) recommendations. Instead of basing the scenarios on recommendations or hypotheses, Masset et al. (2014) worked with self-selected diets in order to propose changes that are more likely to be culturally accepted.

2.1.2 Main methods

Methodologically, LCA has been most widely used to assess food impacts (Baroni et al., 2007; Carlsson-Kanyama, 1998; Davis et al., 2010; González et al., 2011; Wallén et al., 2004), although Input-Output Analysis (IOA) has been presented by some as the most appropriate method for footprint assessment (Duchin, 2005; Wiedmann, 2009) and used by Tukker in the context of food consumption (Tukker et al., 2011). In 2000, Jungbluth compiled a modular LCA for calculating the impacts of the food system in Switzerland (Jungbluth, Tietje, & Scholz, 2000). A hybrid-LCA was used by Virtanen and compared to classic LCAs of meals (Virtanen et al., 2011). To test the food mile concept, Weber and Matthews (2008) also used a hybrid method, using IOA-LCA to assess the total freight needed from production to retail to meet food demand in the United States in 1997. Table 1 offers a detailed picture of the methodologies used for the impact assessment of food consumption.

Correlating health and environmental impacts is often made by considering the nutrient content of different diets (Drewnowski et al., 2015; Green et al., 2015; Heller et al., 2013; Röös, Karlsson, Witthöft, & Sundberg, 2015). Soret used mortality as an indicator of healthiness of three dietary patterns compared with their respective associated GHGEs (Soret et al., 2014) and De Boer used the Body Mass Index (De Boer, Schösler, & Aiking, 2014).

2.1.3 Main findings

Most studies agree that meat and other animal products are the principal source of negative impacts from the food system in terms of global warming potential (GWP) (Baroni et al., 2007; Jungbluth et al., 2000; Stehfest et al., 2009; Wallén et al., 2004; Weber & Matthews, 2008). Some however argue that reducing meat and dairy consumption, albeit relevant, is not enough to reach a satisfying global reduction of GHGEs (Tukker et al., 2011; Wallén et al., 2004), calling for policy changes regarding production methods (Wallén et al., 2004). The importance of the agricultural stage and agricultural practices is underlined by several studies (Carlsson-Kanyama & González, 2009; Kramer, Moll, Nonhebel, & Wilting, 1999; Virtanen et al., 2011), but the role of transport is also not to be neglected (Coley et al., 2009; Edwards-Jones et al., 2008; Jungbluth et al., 2000).

Finally, aside from carbon emissions and global warming potential, several authors call for research on the bigger picture of food impacts, notably depletion of fish stocks (Gussow, 1995; Tukker et al., 2011), land use (Tukker et al., 2011), water consumption and the ethics behind the production and distribution of food (Baroni et al., 2007).

2.4. Assessments of food-related activities carbon footprint

Fewer studies have been done to assess the environmental impacts arising from home-made food preparation. Carlsson-Kanyama et al. (2003) included it in the system boundaries for their LCA of food products, but did not present the specific emissions arising from that stage. In 2005, Sonesson et al. performed a detailed analysis of the consumer phase including home transport, cooking, storing and wastage and argue for the inclusion of those least investigated activities in food system analyses (Sonesson, Anteson, Davis, & Sjödén, 2005). A similar study followed five years later, when

Kauppinen and colleagues presented a broken-down analysis of the food-preparation activities for the particular case of Finnish households (Kauppinen, Pesonen, Katajajuuri, & Kurppa, 2010). Sonesson and colleagues compared the environmental impacts between homemade and industry-made meals (Sonesson, Mattsson, Nybrant, & Ohlsson, 2005); a similar comparison followed in 2014 (Schmidt Rivera, Espinoza Orias, & Azapagic, 2014).

2.5. Concluding remarks

It appears clear that, although food product impacts have been extensively assessed, there is a need for extending the system boundaries in the studies of food. Compiling food products into specific diets, and then using those diets to build up scenarios have been done several times. Furthermore, the definition of diets has been limited to the food intake; food preparation was systematically assessed in separate studies, or not specifically underlined.

This work aims at adding to the research an assessment of the Norwegian-specific diet and its carbon footprint with an integration of the meal supply processes.

Table 1: Methodology summary form the literature review

	Data	**Allocation / disaggregation**	**Assessment method**	**System boundaries**	**FU**	**Software**	**Impact Ass.**	**Time and Space**	**Other**
Tukker et al. (2011)	E3IOT environmentally extended input output database; Eurostat; Concise European Food Consumption Database; FAO (Food Balance Sheet).	50 food groups. Food processing allocated to each food group, but treated as separate category for households (assume similar impact in all diets).	EIOA. Country cluster for diets. Each cluster based on their ratio vegetal/animal. 3 scenarios, each illustrating diff ratios, hence small dietary shifts.	Does not include water use and land use.	Ratio vegetal/animal per diet	E3IOT & CAPRI (partial equilibrium model for rebound effect). Recommends ReCiPe for impact assessment.	Climate change, ODP, AP, EP, Human toxicity, Photochemical Oxidant Formation, Ecotoxicity, Abiotic Resource Depletion.	Europe, 2003	Takes into account the rebound effect of 1 and 2 order.
González et al. (2011)	Statistics; IPCC (2006); literature; IEA (2009).	Not displayed.	LCI of 84 food items.	From cradle-to-Gothenburg Port	1 kg of food product delivered to Gothenburg port. FU of meat: bon-free carcass. FU of cereals and beans: 1 kg od dry grain at the port (thus excluding packaging).	Not displayed.	Energy use and greenhouse gas emissions.	Sweden, from 2003 to 2011	Takes into account the protein efficiencies.

Virtanen et al. (2011)	EIO-LCA: Finnish economic IO table. LCA: literature; Finnish farming database; Industries; national statistics; personal communications; EcoInvent.	EIO-LCA: disaggregation with help of MFA. Sub-sectors have only 1 sub-prod LCA: not displayed.	EIO-LCA of Finnish food chain and "Lunch plate approach" (process-based LCA of 30 lunch plates).	LCA: From agricultural production to consumer. EIO-LCA: Finnish Food chain, 2005.	LCA: one lunch plate (repeated for 30 different), based on Finnish standards for omnivorous, vegetarian and vegan.	Ecoinvent ENVIMAT-model	CO_2, CH_4, N_2O, PFC, NH_3	Finland, 2005.	Equal amount of energy for all lunch plate, equal share of proteins, carbohydrates, vegetables etc.
Davis et al. (2010)	Survey, reports and Ecoinvent.	Economic.	LCA of 4 meals composed of different amounts of soybeans and peas both in terms of direct and indirect consumption.	From Cradle-to-grave. Production of food, fertilizers and fuels. Packaging (production and waste). Electricity &heat. Transport. Sewage treatment.	A meal served at the household (with the same nutritional value).	Not displayed. Used Ecoinvent database.	Use of renewables, of non-renewables, GWP, Photo oxidant formation potential, NOx level, stratospheric ozone DP, EP, AP.	Spain & Sweden, 2005 -2006	
Weber & Matthew (2008)	US input-output accounts for total economy-wide household expenditure on food and food availability statistics in the US.	By caloric ratios of the primary food group.	IO-LCA.	Total freight distance from production to retail to meet food demand in 1997.	Economy-wide and per-capita data were normalized to the common unit of household.	Not displayed.	Results presented in CO_2 equivalent.	USA 1997	Only assesses transport-related emissions

Baroni et al. (2007)	Average Italian food consumption. Textbooks and scientific papers.	Subsume food products into categories, with weighting depending on consumption data.	LCAs of 3 weekly diets: omnivorous, vegetarian, vegan; combined with 2 production method: conventional and organic.	Not displayed.	A weekly diet with a certain energetic and nutrient content.	SimaPro5, Eco indicator 99 for assessment phase.	Damages to human health, damages to ecosystems quality, damages to resources. Analyzed with the 3 cultural approaches.	Italy	Results are given in points. Results also calculated for the conventional Italian diet for comparison.
Wallén et al. (2004)	National statistics, published studies, manufacturers.	Not displayed.	LCA of food groups and produces.	Processes included in the cultivation and distribution of food.	Energy use and emission of GHG for food production, processing, and distribution needed for food consumption per capita in Sweden in 1 year.	Not displayed.	Energy use and CO2 equivalents.	Sweden, 1999.	Compare the consumption level of 1999 of different food groups with a consumption level suggested by another study and presented as a sustainable diet.
Jungbluth et al. (2000)	Review of 150 studies investigating life cycle of food products; Swiss agricultural production inventory; Swiss consumption patterns.	5 modules: type of agricultural practice, origin, packaging material, type of preservation and consumption.	Modular LCA.	From cradle-to-grave: From agricultural production to the end-of-life management.	1 kg of purchased product.	Eco-indicator 95, Ecoinvent.	All impact categories.	Switzerland, 1999	Also took into account different agricultural production methods.
Carlsson-Kanyama (1998)	Previous studies	Not displayed.	LCA of carrots, tomatoes, potatoes, pork, rice and dry peas	All processes from the production chain prior to the consumer's purchase of food.	1 kg of the produce sold by Swedish retailers during the early mid-1990s.	Not displayed.	Results presented in CO2 equivalents with a 20 year time perspective.	Sweden mid-1990s.	Results for GHGE and energy consumption.

3. Methods

3.1 Carbon footprinting of current Norwegian food-related habits

3.1.1 Food consumption carbon footprinting

The first step of the work was to assess the carbon footprint of current average diets in Norway. To do so, data were needed on two sides: the average food consumption per food item and the life-cycle carbon intensities per food item.

3.1.1.1. Food consumption data

Food consumption data was taken from the Norwegian dietary survey "Norkost" (Totland, Melnæs, Lundberg-Hallen, Helland-kigen, & Lund-blix, 2012), which discloses the average food intake of Norwegians aged 18-70, broken down by gender, age group ('18-29','30-39','40-49',50-59','60-70'), as well as households type ('family with kids', 'family without kids', 'single'). Food products are grouped in 16 categories while beverages are grouped in 7 categories. As water is an essential human nutrient, its carbon footprint was excluded from this study. Thus 22 food and beverages categories are retained for the present work.

The greatest level of detail was desirable in order to provide an analysis as precise as possible. For this reason, national statistics on food and beverages consumed per person and per year were used to complement the Norkost survey (SSB Table 10249). This was the case for 'fresh/frozen vegetables' to which 5 vegetables types were added, for 'fresh fruit and berries' to which 7 types of fruits were added, for 'pure red meat' with the addition of 3 meat types, 'sugar, honey, sweet spreads' with 2 items added and 'chocolate, candy' with also 2 items added. This gives a total of 19 food items taken from SSB to complement Norkost food categories.

The food items were grouped in 16 categories, some of which had up to 5 subcategories. In total, 85 food items were specified in the present analysis.

Beverages were grouped into 6 categories, including a total of 15 products.

There are thus a total of 22 food and beverage categories and 100 broken-down items. Three beverages categories (‘beer, ‘wine’ and ‘liquor’) and two food categories (‘juice and mash’ and ‘eggs’) are not further broken-down.

It was systematically ensured that the consumption intake of a food/beverage category in grams was equal to the sum of the intake of its components.

3.1.1.2. Carbon intensities data

Carbon intensities were collected for each of the food and beverage items presented above. Existing literature was the main source of data, complemented by Environmental Product Declarations (EPDs) and own assumptions where information was lacking. Carbon intensities at the aggregate level of each category was calculated as the weighted average of its components relative to the consumption values.

Seventy-three food products intensities were collected from existing literature, among which seven from EPDs. Assumptions based on similar food products helped assign carbon intensities for 27 food items, among which 4 were averages of other food items and 23 were assumed equal as another food item. Three food items were assessed through informed guesses.

Carbon intensities are given in CO_2-equivalents per food volume, noted CO_2-e, as carbon dioxide is the reference gas to measure greenhouse effect of other gases

3.1.1.3. Calculations

Carbon footprints of current diets were assessed by multiplying the two types of information previously collected (consumed amounts and carbon intensity) of each food product and category. Results are given both as a broken-down table comprising all the food and beverage types and as a table of aggregates only including the 22 food and beverage categories.

3.1.2 Food waste carbon footprinting

Impacts from food wastes were calculated using the model built for the carbon footprint of diets. Information on food waste in Norway is scarce but European food waste levels were found in an FAO report on global food losses (Gustavsson, Cederberg, & Sonesson, 2011). The report gives percentages in weight of food wasted at the consumer stage and per food category. It presents seven categories ('cereals', 'roots & tubers', 'oilseeds & pulses', 'fruits & vegetables', 'meat', 'fish & seafood' and finally 'milk'). To assess food waste, these categories were matched to the ones used in the present work. For any of the 22 categories for which the waste percentage could not be matched, conservative assumptions were made and the lowest percentage given by the report – that is 4% for 'oilseeds & pulses'- was applied. This is the case for 'sugar & sweets', 'miscellaneous', 'soft drinks and soda', 'eggs', 'cakes' and 'grain products'. Goods with long shelf-lives such as tea, coffee and alcohols were assumed to have a waste degree of 1%.

Based on the average Norwegian diet gathered for the assessment of its carbon footprint, waste percentages were used to increase their respective food category consumption level. Food wastes are thus allocated to an increase in food consumption, acting as an unused demand for food. The artificially increased food consumption was then multiplied by the carbon intensities (in kg CO_2-e/ kg product) presented in the second paragraph of this section, thus giving results representing a diet accounting for food wastes.

3.1.3 Food supply activities carbon footprinting

Apart from the emissions arising from the food items themselves, it was interesting to investigate the emissions coming from food-related activities that are food transportation, storage and preparation from a household.

In order to assess the carbon footprint of such activities a simple life cycle analysis (LCA) was conducted. Life cycle analysis is a tool to assess environmental impacts arising all along a product or an activity's life cycle in a holistic manner, i.e. from its production phase, including extraction of materials, to its end-of-life. The LCA conducted here only assessed the use phase of the selected processes. This was a conscious choice based on the goal and scope of the present work that is to evaluate the carbon footprint of diets and its reduction potential at a household level. The composition of a diet, as well as the means used to transport, store and prepare the food are variables upon which a household can make conscious choices. However, an average household cannot influence the production and end-of-life processes of appliances and food products that happen at an industrial and agricultural level. As such, it was deemed more relevant to focus the analysis on variables of a diet that can be influenced by personal choices.

LCAs are built with matrices representing the foreground processes requirements (A_{ff}), the background processes requirements (A_{bb}) and the upstream inputs of background processes to foreground processes (A_{bf}) (Strømman 2010).

The system boundaries were drawn to cover the most relevant processes in the Norwegian context. Ten processes composed the foreground: gas stove/oven, electric stove/oven, microwave, fridge without a freezer ('fridge w/o freezer'), fridge with a freezer ('fridge w/ freezer'), separate freezer ('freezer'), electric car, conventional car, food preparation, food storage, food transport and finally food supply. Three processes composed the background: gas, electricity and fuel. Figure 1 illustrates the system thus composed.

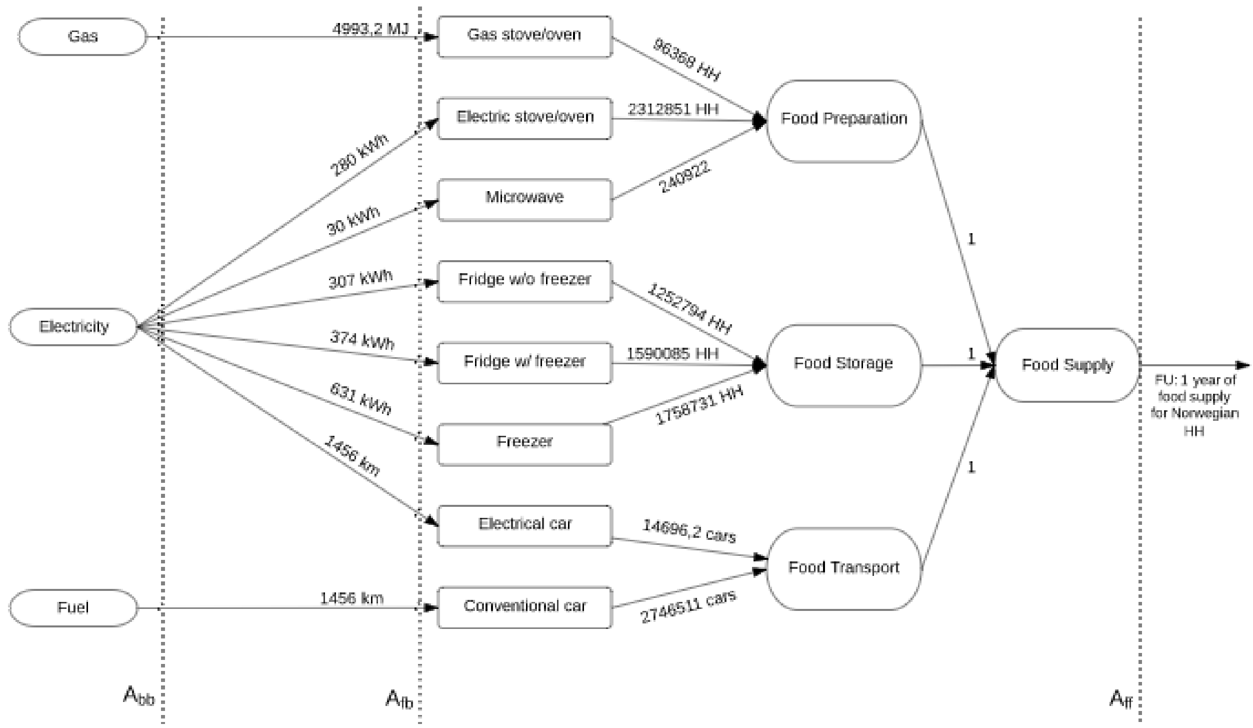

Figure 1: Food supply system for all Norwegian households

The functional unit (FU) designates the external demand placed upon the system and is here defined as one year of food supply for all Norwegian households.

Data were taken from national statistics and from a SINTEF report (Hanne, Rosenberg, & Feilberg, 2010). Background processes were selected from the ecoinvent 22 database (ecoinvent 2015). The Arda software (Majeau-Bettez & Strømman 2014) was chosen to build the system and compute the results. Figures 2 and 3 show respectively the foreground requirement matrix (A_{ff}) with the associated final demand (y_f) and the requirements placed by the foreground to the background matrix (A_{bf}) as they will be read by Arda.

In this Sheet, you enter your foregronk), and your foreground requirement matrix (A_ff, orange)

	Label (PRO_f):			y_f:		A_ff: 1	2	3	4	5	6
	FULL NAME	PROCESS ID				Food sup	Food pre	Food sto	Food tra	Gas stov	Electric s
1	Food supply	10001		1							
2	Food preparation	10002				1					
3	Food storage	10003				1					
4	Food transportation	10004				1					
5	Gas stove/ oven	10005					96368,8				
6	Electric stove / oven	10006					2312851				
7	Microwave	10007					240922				
8	Fridge w/o freezer	10008						1252794			
9	Fridge w/ freezer	10009						1590085			
10	Freezer	10010						1758731			
11	Electrical car	10011							14696,2		
12	Conventional car	10012							2746511		

Figure 2: Foreground to foreground requirement matrix

Background Name *Comment*	Foreground Process Name *Comment*	(Arda ID) BACKGROUND ID	(Process ID) FOREGROUND ID	AMOUNT	Unit *Comment*
Gas	Gas stove/oven	2098	10005	4993,2	MJ
Electricity	Electric stove/oven	1124	10006	280	kwh
	Microwave	1124	10007	30	kwh
	Fridge w/o freezer	1124	10008	307	kwh
	Fridge w/ freezer	1124	10009	374	kwh
	Freezer	1124	10010	631	kwh
Electricity for car	Electric car	2764	10011	1456	km
Fuel	Conventional car	2755	10012	1456	km

Figure 3: Background to Foreground requirement matrix

Ecoinvent processes are the following:

- 2098: Natural gas, high pressure/ at consumer/ DK/MJ.
- 1124: Electricity, low voltage/ at grid/ NO/kWh
- 2764: Operation, passenger car/ electric/ LiMn2O4 / CH/ km
- 2755: Operation, passenger car/ RER / km.

3.1.3.2. Sensitivity analysis

From the results of the baseline analysis, it was obvious that the most influential process was the use of conventional cars to transport food from the groceries. The paper used for data on car trips conducted a survey in Sweden in 2005, which specifically assessed trips with the sole purpose of grocery shopping. However, accounting so means leaving out combined trips, such as going back home after work and taking a detour to shop for food on one's way. The distance driven to transport food from the grocery shop to the house is then substantially uncertain, in addition to being the most significant process in the food supply system. This is why it was of particular importance to assess the system's sensitivity to this parameter.

To do so the distance driven was increased by 10% in the background to foreground requirement matrix (A_{bf}) while leaving all other parameters equal to the baseline. A new analysis was launched with Arda, and total impacts between the new system and the baseline were compared.

Another variable that was judged potentially significant is the choice of the Ecoinvent process for electricity use. This background process is determinant for 5 of the foreground processes and it is unsure whether the one chosen is the best representative of the actual electricity use and its associated carbon intensity. To test the sensitivity of the system to this background process, another analysis was launched replacing "electricity, low voltage/ at grid/ NO/kWh" by "electricity mix/ NO/ kWh" in Arda.

A last potentially significant uncertainty is the ownership of gas stoves and ovens. The value used in the baseline is an assumption made from the ownership value of electric stoves and ovens found in the SINTEF report. There, electric oven/stoves are said to have an ownership of 96%; the remaining 4% was assumed to be ownership of gas stoves and ovens, thus assuming that any household have either one of the two systems, leaving no ownership to for instance wood-fired stoves. To assess the error margin that this assumption could bring to the results, a new analysis with an ownership of 1% gas stoves and 99% electric stoves was launched.

3.2. Carbon footprinting of reduction scenarios

3.2.1. Diet scenarios

Reduction potentials were computed through the model made to assess the current carbon footprint of diets. This assessment was made on a weight basis, though to ensure building realistic scenarios, all values in kilograms from the original model were converted to kilocalories. The total calories intake was kept constant for all scenarios - but the first one (see section 3.3.1 paragraph "Scenario 1: 2300 kcal") - in order for them to be comparable.

In order to do the conversion, calories intensities in kcal/100g food were gathered from Matvaretabellen for each food products (Matvaretabellen 2014). Calorie intensities of the food groups are the simple average calories of their components. Table 1 gives an insight of the three different types of multipliers used for this work. It presents the multipliers of the first 21 products and 5 food categories.

Table 2: Excerpt of the multipliers tab

Food type	GWP (kg CO2e / kg food)	kcal / 100g food	CO2 / kcal
Bread	**9,7E-01**	**2,8E+02**	**3,5E-04**
Fine bread	5,4E-01	2,2E+02	2,5E-04
Half wholemeal bread	5,5E-01	2,4E+02	2,3E-04
Wholemeal bread	1,4E+00	2,5E+02	5,9E-04
Hard bread, loaf	7,1E-01	4,0E+02	1,8E-04
Grain products	**1,1E+00**	**3,1E+02**	**3,7E-04**
Flour, rice, pasta, dry w	1,3E+00	1,4E+02	9,4E-04
Breakfast cereals, swee	1,0E+00	3,8E+02	2,7E-04
Breakfast cereals, unsw	7,9E-01	4,0E+02	2,0E-04
Pasta dish/ pie	8,1E-01	3,0E+02	2,7E-04
Cakes	**1,0E+00**	**3,6E+02**	**2,9E-04**
Buns, waffles	9,1E-01	2,5E+02	3,7E-04
Cookies, dry biscuits	2,6E+00	4,5E+02	5,9E-04
Cakes etc	9,1E-01	3,8E+02	2,4E-04
Potatoes	**3,3E-01**	**2,5E+02**	**1,3E-04**
Fresh potatoes	1,7E-01	7,2E+01	2,4E-04
French fries	2,4E+00	3,3E+02	7,2E-04
Mashed potato powder	1,1E+00	3,4E+02	3,3E-04
Vegetables	**9,6E-01**	**7,3E+01**	**1,3E-03**
vegetables, fresh/ froze	**1,1E+00**	**7,7E+01**	**1,4E-03**
... Leaf and stem vegeta	3,3E+00	2,8E+01	1,2E-02
... Cabbages	1,2E-01	3,2E+01	3,8E-04
... Vegetables grown for	1,8E+00	2,2E+01	8,3E-03
... Root crops, non-starcl	5,0E-01	2,2E+01	2,3E-03
... Dried vegetables	1,8E+00	2,8E+02	6,4E-04
vegetables, preserved	3,0E-01	2,0E+01	1,5E-03
Peas / beans, dry weigh	4,9E-01	1,1E+02	4,6E-04

The analysis of current diets was run a second time based on kcal to ensure consistency of the model. Results found in the two units however differ by emissions coming from tea consumption, as tea is assumed to have no calories in Matvaretabellen.

For practical reasons all scenarios were built at the aggregate level of food products (22 categories) and for the population groups of men, women as well as for the average of the two. The baseline scenario is the current consumption of these selected population groups.

Now will be introduced each scenario and its specific calculations.

3.2.1.1. Scenario 1: *2300 kcal*

A first observation from the baseline is that average men and women's diet reach kcal intakes that exceeds the recommended calories intake (USDA, 2010). As such it was relevant to evaluate the carbon benefits of eating the recommended amount of calories without necessarily changing the structure of one's diet. To do so, the baseline diet was rescaled to reach a 2600 kcal for men and 2000 kcal for women, thus giving a 2300 kcal in average. Each food category keeps the same contribution percentage in the diet as in the baseline. Put in simple words, people don't change their habits but only resize their portions.

Rescaling was achieved as follow:

$$kcal_1^n = (kcal_0^n * 2300)/kcal_0^{tot}$$

Where

- $Kcal_1^n$ expresses the amount of kcal ingested from the n^{th} category after rescaling (scenario 1)
- $Kcal_0^n$ expresses the amount of kcal ingested from the n^{th} category in the baseline (scenario 0).
- $Kcal_0^{tot}$ expresses the total kcal ingested in the baseline.

The new intakes were then multiplied with the CO_2 intensities of each category as well as the grams intensity.

3.2.1.2. Scenario 2: Pescetarianism

This scenario analyzes a diet from which meat consumption is excluded. That is to say that pescetarians eat animal products such as fish, eggs and dairies but stay away from meat and meat products. To make the assessment, the intake percentage of ‘meat and meat products’ was set to 0. To keep the kcal constant, the original contribution of meat was redistributed to vegetables, fish and eggs. This was done by raising the contribution percentage of these categories by the original contribution percentage of ‘meat and meat products’ divided by 3.

Redistributing the calories from meat was done as follow:

$$kcal_2^n = kcal_0^{tot} * (P_0^n + (P_0^8/3))$$

Where

- $Kcal_2^n$ is the kcal ingested in scenario 2 coming from the n^{th} category.
- P_0^n is the original contribution percentage of the n category.
- P_0^8 is the original contribution percentage of the 8^{th} category, namely ‘meat and meat products’.
- $Kcal_0^{tot}$ expresses the total kcal ingested in the baseline.

New intakes where then each multiplied by CO_2 intensities and grams intensities.

3.2.1.3. Scenario 3: Vegetarianism

This scenario simulates a diet that excludes both meat and fish products. The same reasoning as for building the second scenario was applied.

The contribution percentages of fish and meat products in the baseline diet were summed up to give the proportion of calories intake to be redistributed in the scenario. It was chosen to redistribute the lost calories by increased intakes of ‘grain products’, ‘vegetables’, ‘eggs’, ‘milk and yoghurt’, and ‘cream and cream products’.

It is assumed that a vegetarian diet is based on a high intake from vegetables, as indicated in the dietary recommendations from USDA (2010). As meat and fish products make up together for 15% of the calories intake in the baseline, each of the category mentioned above was augmented by $\frac{15}{7}$ percentage points, except for the 'vegetables' category which was augmented by $(\frac{15}{7} \times 3)$ percentage points. As USDA recommendations are given on a weight basis the values in grams allow to verify the validity of the scenario. Table 2 shows the intakes in grams of each category for the baseline and the vegetarianism scenario.

Meat and fish categories were both set to 0. The redistribution in the selected categories mentioned above was done as follow:

$$Kcal_3^n = kcal_0^{tot} * (P_0^n + \frac{15}{3})$$

Where

- $Kcal_3^n$ is the kcal ingested in scenario 3 coming from the n^{th} category.
- P_0^n is the original contribution percentage of the n category.
- $Kcal_0^{tot}$ expresses the total kcal ingested in the baseline.

Redistribution in the vegetables category was done as follow:

$$Kcal_3^5 = kcal_0^{tot} * (P_0^5 + (\frac{15}{3} \times 3))$$

Where

- $Kcal_3^5$ is the kcal ingested in scenario 3 coming from the 5^{th} category, namely 'vegetables'.

Table 3: Values in grams of the vegetarian scenario compared to the baseline

Scenarios		Baseline								Vegetarianism							
Food types	Kcal intensity	Daily Intake in kcal			Percentage average intake	Daily Intake in grams			Percentage weight	Daily Intake in kcal			Percentage intake	Daily Intake in grams			Percentage weight
	kcal/grams	Men	Women	Average		Men	Women	Average		Men	Women	Average		Men	Women	Average	
Bread	2,77E+00	629	399	514	19%	227	144	186	8%	589	443	520	19%	212	160	188	8%
Grain products	3,05E+00	140	104	122	4%	46	34	40	2%	206	155	182	7%	68	51	60	3%
Cakes	3,57E+00	128	121	125	5%	36	34	35	1%	143	108	126	5%	40	30	35	2%
Potatoes	2,49E+00	209	127	168	6%	84	51	68	3%	192	145	170	6%	77	58	68	3%
Vegetables	7,29E-01	113	113	113	4%	155	155	155	6%	329	248	291	11%	451	340	399	18%
Fruit and berries	1,22E+00	343	352	348	13%	281	288	285	12%	398	300	352	13%	326	246	288	13%
Juice and mash	5,00E-01	57	50	54	2%	114	100	107	4%	35	26	31	1%	70	53	62	3%
Meat and meat products	2,02E+00	365	232	299	11%	181	115	148	6%	0	0	0	0%	0	0	0	0%
Fish and fish products	1,78E+00	141	100	120	4%	79	56	68	3%	0	0	0	0%	0	0	0	0%
Eggs	1,42E+00	40	33	36	1%	28	23	25	1%	107	81	95	3%	76	57	67	3%
Milk and yoghurt	5,16E-01	199	129	162	6%	385	249	314	13%	252	190	222	8%	488	368	431	19%
Cream and cream products	3,02E+00	70	63	67	2%	23	21	22	1%	143	108	126	5%	47	36	42	2%
Cheese	3,59E+00	161	154	158	6%	45	43	44	2%	181	136	160	6%	50	38	45	2%
Butter, margarin, oil	5,53E+00	216	138	199	7%	39	25	36	1%	228	172	201	7%	41	31	36	2%
Sugar, sweets	4,14E+00	70	74	72	3%	17	18	18	1%	83	62	73	3%	20	15	18	1%
Diverse	1,70E+00	36	32	35	1%	21	19	21	1%	40	30	35	1%	23	18	21	1%
Coffee	2,00E-02	12	9	10	0%	592	454	523	21%	2	2	2	0%	120	90	106	5%
Tea	0,00E+00	0	0	0	0%	0	0	0	0%	0	0	0	0%	0	0	0	0%
Saft/brus (soda)	2,73E-01	77	55	66	2%	282	201	242	10%	76	57	67	2%	277	208	244	11%
Beer	4,35E-01	57	16	36	1%	132	37	83	3%	41	31	37	1%	95	72	84	4%
Vin	7,00E-01	31	32	32	1%	44	46	45	2%	36	27	32	1%	52	39	46	2%
Liquor	2,85E+00	11	6	9	0%	4	2	3	0%	10	7	9	0%	3	3	3	0%
Total Intake		3105	2339	2742	100,0%	2815	2115	2464	100%	3092	2329	2730	100%	2537	1911	2241	100%

3.2.1.4. Scenario 4: *Veganism*

This scenario tests the impact of excluding any animal product, namely meat, fish, eggs, dairies and honey. Honey was here not excluded for the reason that it is aggregated in the ‘sugar and sweet’ category. However this is a minor shortcoming because sugar products only makes up for 0.08% of the food consumed by an average Norwegian, which corresponds to 0.1% of the total carbon footprint. Butter was also not possible to exclude because it is comprised with margarine in the category “butter, margarine and oil”. The broken-down baseline diet is not disaggregated enough to be able to isolate butter from margarine. It would by consequence be not realistic to set ‘butter and margarine’ to 0 since vegans need an intake of fat, which comes for a big part from oil and margarine.

The categories that were removed from this scenario are thus ‘meat and meat products’, ‘fish and fish products’, ‘eggs’, ‘milk and yoghurt’, ‘cream and cream products’ and finally ‘cheese’. Animal products make up together for 31% of the baseline kcal intake. The compensating foods in this scenario are ‘grain products’, ‘cakes’, ‘potatoes’, ‘vegetables’, ‘fruit and berries’ and ‘juice and mash’. Here too a special emphasis was put on the ‘vegetables’ category. This diet has similar calories intake proportion from ‘bread’, ‘vegetables’ and ‘fruit and berries’.

The redistribution to ‘grain products’, ‘cakes’, ‘potatoes’, ‘fruit and berries’ and ‘juice and mash’ was done as follow:

$$Kcal_4^n = kcal_0^{tot} * (P_0^n + \frac{31}{8})$$

Where

- $Kcal_4^n$ is the kcal ingested in scenario 4 coming from the n^{th} category.
- P_0^n is the original contribution percentage of the n category.
- $Kcal_0^{tot}$ expresses the total kcal ingested in the baseline.

The redistribution to ‘vegetables’ was done as follow:

$$Kcal_4^5 = kcal_0^{tot} * (P_0^5 + (\frac{31}{8} \times 3))$$

Where

- $Kcal_4^5$ is the kcal ingested in scenario 4 coming from the 5th category, namely 'vegetables'.

3.2.1.5. Scenario 5: Vegetarian dinners

Here is tested a diet that only excludes meat and fish at dinners but allows those products for other meals of the day. It was assumed that dinner accounts for 60% of the kcal intake in a day. To test the impacts of vegetarian dinners, both meat and fish categories were thus decreased by 60%.

To compensate for the calories lost, two steps were necessary. First the percentage loss in kcal brought by the decrease in meat and fish intakes was calculated. This corresponds to a 9% loss of calories. To spread this 9% of missing intake the same method as for the second, third and fourth scenarios was used, that is to increase the contribution percentage of compensating categories by the percentage points lost divided by the number of compensating categories. Here an equal increase of intake from 'bread', 'grain products', 'potatoes' and 'vegetables' was assumed. Assuming so implies that a person shifting from the current average Norwegian diet to such a diet will not fundamentally change his/her cooking habits and will rather increase the portions of food items that usually accompany meat at dinner, namely carbohydrates, such as bread. Redistribution was done as follow:

$$Kcal_5^n = kcal_0^{tot} * (P_0^n + (\frac{P_0^{tot} - P_5^{tot.org}}{4}))$$

Where

- $Kcal_5^n$ expresses the amount of kcal ingested from the nth category after rescaling (scenario 5)
- $Kcal_0^{tot}$ expresses the total kcal ingested in the baseline
- P_0^n is the original contribution percentage of the n category
- P_0^{tot} is the total percentage intake of the baseline coming from all food and beverages categories (thus equal to 100%).

- $P_5^{tot.org}$ is the total percentage intake of the 5th scenario coming from all food and beverages categories after decreasing meat and fish intake from dinners but keeping a total kcal constant form the baseline (thus equal to 100% - 91%).

3.2.1.6. Scenario 6: Decreased dairy intake

As ‘milk and yoghurt’ and ‘cheese’ are respectively the second and third most impacting food categories in the current diet, this scenario tests the benefits of decreasing calories intake of dairies by 50%.

The same method as for the 5th scenario - *vegetarian dinners* - was applied. The decreased categories are ‘milk and yoghurt’, ‘cream and cream products’ and ‘cheese’ by 50%. Compensating calories come from ‘bread’, ‘vegetables’, ‘eggs’ and ‘butter, margarine, oil’, which were all equally increased. As mentioned for scenario 4, butter as a product is not possible to disaggregate from margarine. Yet, it is realistic to assume that a decrease in cream products will likely be replaced by an increase in other fat products, such as margarine or oil. Cream and cream products, as well as cheese, serve approximately the same purpose in a diet than products comprised in ‘butter, margarine and oil’ category, such as preparing a sauce, accompanying a meat or fish or spreading on a slice of bread.

All scenarios were multiplied by 30.5 and by 365 to show results respectively per month and per year.

3.2.2. Food supply scenarios

In order to test the best combination of appliances and car choices, a series of seven scenarios were prepared. The functional unit was changed to ‘a year of food supply for one Norwegian household’. The foreground requirements were changed from the baseline in order to meet the needs of a single household. To present the method more explicitly, the first scenario will be taken as an example: it represents a household owning 1 gas stove, 1 microwave, 1 fridge with freezer, 1 extra freezer and 1 conventional car. Table 3 shows the modified foreground system.

Table 4: Foreground to foreground matrix for scenario A

Label (PRO_f):		y_f:		A_ff:	1	2	3	4
FULL NAME	PROCESS ID				Food sup	Food pre	Food sto	Food trai
Food supply	10001		1					
Food preparation	10002				1			
Food storage	10003				1			
Food transportation	10004				1			
Gas stove/ oven	10005					1		
Electric stove / oven	10006					0		
Microwave	10007					1		
Fridge w/o freezer	10008						0	
Fridge w/ freezer	10009						1	
Freezer	10010						1	
Electrical car	10011							0
Conventional car	10012							1

The corresponding system is displays in figure 4.

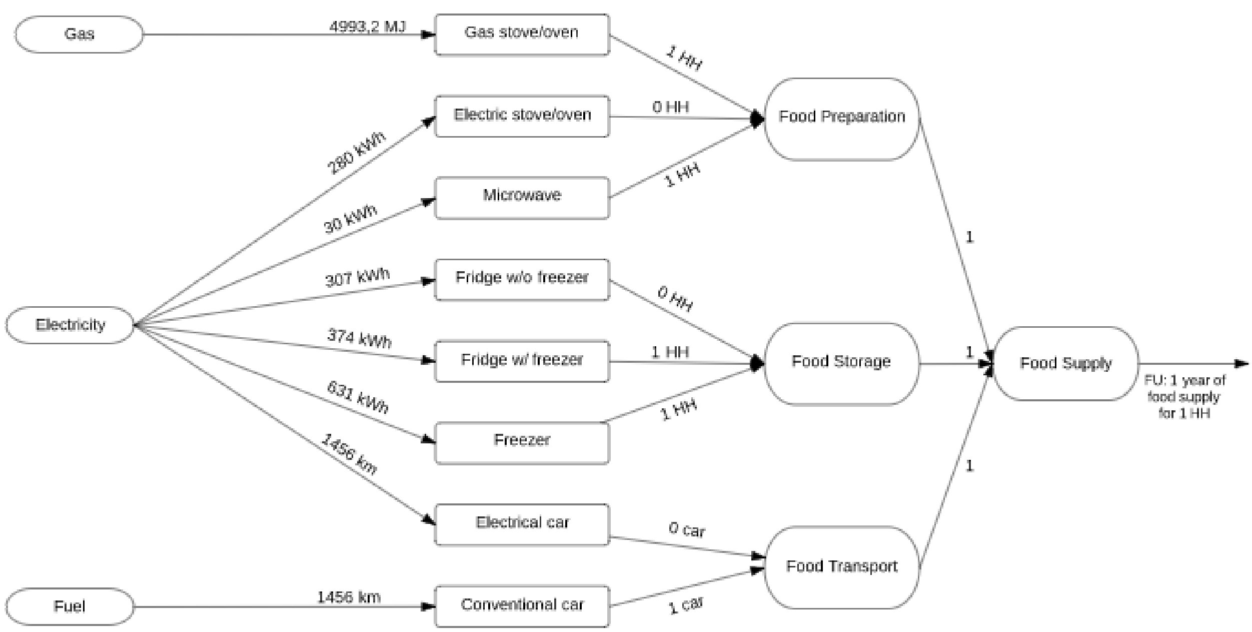

Figure 4: Food supply system for scenario A

Such modifications to the foreground allowed for the construction of six other scenarios. Each corresponding foreground matrices may be found in Appendices A - G.

A short summary of scenarios is shown in table 4.

Table 5: Overview of ownerships made for each scenario

	Gas stove/oven	Electric stove/oven	Microwave	Fridge w/o freezer	Fridge w/ freezer	Separate freezer	Electric car	Conventional car
A	x		x		x	x		x
B		x	x		x	x		x
C		x	x	x		x		x
D		x	x		x			x
E		x	x		x	x	x	
F		x	x	x		x	x	
G		x	x		x		x	

With 8 variables with which to compose scenarios, there are 8! = 40 320 different combinations possible. The seven selected here are believed to be the most interesting for the purpose of this work and/or closer to reality in the Norwegian context.

4. Results

The results obtained through the methods aim at answering the main research question: What is the average carbon footprint of Norwegian diets and how can it be reduced?

4.1. Assessment of the current carbon footprint of Norwegian food habits

4.1.1 Food consumption carbon footprint assessment

4.1.1.1. Overall results

According to the present analysis, an average Norwegian diet leads to emissions of 1233 kg CO_2-e/ year. This is equivalent to 3.38 kg CO_2-e/ day or 102.7 kg CO_2-e/ month.

On average, women eat less than men, which consequently leads to a food consumption carbon footprint 1.3 times lower compared to the one of men. An average man's food consumption leads to emissions of 1.4 tCO_2-e/ year while a woman's food consumption carry embodied emissions of 1.0 tCO_2-e/ year. On average, a woman's diet thus leads to 26% less emissions than a man's diet, equal to 367 kg CO_2-e/ year of saved emissions.

Accounting for the Norwegian population in 2015 (SSB Table 05810), the Norwegian male population' food consumption leads to emissions of 3.7 Mt CO_2-e/ year while the Norwegian female population' food consumption leads to emissions of 2.7 Mt CO_2-e per year. In total, 6.4 Mt CO_2-e per year are emitted due to Norwegian food consumption.

Table 5 provides a snapshot of the results in g CO_2-e arising from the food consumption of some 30 food products and 6 categories.

Table 6: Snapshot of the current average Norwegian diets carbon footprint results

Food type	CO2 in grams/ grams of eaten food			18-29		30-39		40-49		50-59		60-70		Family with kids		Family without kids		Single	
Annual Carbon Footprint	50%	50%	100%	23%		20%		21%		19%		17%		35%		21%		40%	
	Men	Women	Total	M	W	M	W	M	W	M	W	M	W	M	W	M	W	M	W
Bread	80,0	50,8	65,4	96,3	53,9	86,4	55,7	79,7	51,1	74,4	49,0	71,2	45,5	83,6	52,5	76,9	49,0	78,6	49,0
Fine bread	8,5	5,1	6,8	10,2	5,5	9,2	5,6	8,5	5,2	7,9	5,0	7,6	4,6	8,9	5,3	8,2	5,0	8,4	5,0
Half wholemeal bread	14,0	6,8	10,4	16,8	7,2	15,1	7,5	13,9	6,8	13,0	6,6	12,5	6,1	14,6	7,0	13,4	6,6	13,8	6,6
Wholemeal bread	53,8	34,8	44,3	64,7	37,0	58,1	38,2	53,6	35,1	50,0	33,6	47,9	31,2	56,2	36,0	51,7	33,6	52,8	33,6
Hard bread, loaf	3,1	4,6	3,9	3,7	4,9	3,3	5,1	3,1	4,7	2,9	4,5	2,8	4,2	3,2	4,8	3,0	4,5	3,0	4,5
Grain products	18,9	14,0	16,4	27,7	15,2	24,8	19,2	16,8	15,2	16,8	10,0	13,0	10,0	21,0	14,8	16,8	12,0	18,1	15,2
Flour, rice, pasta, dry weight (tørrvekt	11,2	9,7	10,5	16,4	10,6	14,7	13,4	10,0	10,6	10,0	7,0	7,7	7,0	12,5	10,3	10,0	8,4	10,7	10,6
Breakfast cereals, sweetened	3,7	2,2	2,9	5,4	2,4	4,8	3,0	3,2	2,4	3,2	1,6	2,5	1,6	4,1	2,3	3,2	1,9	3,5	2,4
Breakfast cereals, unsweetened	2,6	1,7	2,2	3,8	1,9	3,4	2,4	2,3	1,9	2,3	1,2	1,8	1,2	2,9	1,8	2,3	1,5	2,5	1,9
Pasta dish/ pie	1,2	0,6	0,9	1,7	0,6	1,6	0,8	1,1	0,6	1,1	0,4	0,8	0,4	1,3	0,6	1,1	0,5	1,1	0,6
Cakes	13,6	12,8	13,2	14,3	10,9	9,8	13,2	14,3	12,8	12,4	12,8	15,8	14,3	14,0	12,8	15,1	14,0	9,4	10,9
Buns, waffles	5,6	5,0	5,3	6,0	4,2	4,1	5,1	6,0	5,0	5,2	5,0	6,6	5,6	5,8	5,0	6,3	5,4	3,9	4,2
Cookies, dry biscuits	2,9	1,9	2,4	3,1	1,6	2,1	2,0	3,1	1,9	2,6	1,9	3,4	2,2	3,0	1,9	3,2	2,1	2,0	1,6
Cakes etc	5,3	5,6	5,5	5,6	4,8	3,8	5,8	5,6	5,6	4,9	5,6	6,2	6,3	5,5	5,6	5,9	6,1	3,7	4,8
Potatoes	10,1	6,2	8,1	7,0	4,9	7,8	5,8	9,0	5,9	11,5	6,4	13,4	7,6	8,8	6,0	11,9	6,8	10,0	5,5
Fresh potatoes	4,8	2,9	3,8	3,3	2,3	3,7	2,7	4,3	2,8	5,4	3,0	6,3	3,6	4,1	2,9	5,6	3,2	4,7	2,6
French fries	5,2	2,6	3,9	3,6	2,1	4,0	2,4	4,6	2,5	5,9	2,7	6,9	3,2	4,5	2,5	6,1	2,9	5,1	2,3
Mashed potato powder	0,4	0,4	0,4	0,3	0,3	0,3	0,4	0,4	0,4	0,5	0,4	0,5	0,5	0,4	0,4	0,5	0,4	0,4	0,4
Vegetables	54,3	54,3	54,3	62,7	48,3	53,9	53,9	53,2	57,4	55,7	53,9	49,7	55,0	54,6	54,3	54,3	53,2	54,3	57,4
vegetables, fresh/ frozen	48,6	53,4	51,0	56,2	47,6	48,3	53,1	47,7	56,5	49,9	53,1	44,5	54,1	48,9	53,4	48,6	52,4	48,6	56,5
... Leaf and stem vegetables	6,8	7,5	7,2	7,9	6,7	6,8	7,5	6,7	7,9	7,0	7,5	6,3	7,6	6,9	7,5	6,8	7,4	6,8	7,9
... Cabbages	0,8	0,9	0,9	1,0	0,8	0,8	0,9	0,8	1,0	0,8	0,9	0,8	0,9	0,8	0,9	0,8	0,9	0,8	1,0
... Vegetables grown for their fruit	31,7	34,9	33,3	36,7	31,0	31,5	34,6	31,1	36,9	32,5	34,6	29,0	35,3	31,9	34,9	31,7	34,2	31,7	36,9
... Root crops, non-starchy bulbs and n	8,5	9,4	9,0	9,9	8,3	8,5	9,3	8,4	9,9	8,7	9,3	7,8	9,5	8,6	9,4	8,5	9,2	8,5	9,9
... Dried vegetables	0,7	0,8	0,7	0,8	0,7	0,7	0,8	0,7	0,8	0,7	0,8	0,6	0,8	0,7	0,8	0,7	0,8	0,7	0,8
vegetables, preserved	3,4	2,2	2,8	3,9	1,9	3,4	2,2	3,3	2,3	3,5	2,2	3,1	2,2	3,4	2,2	3,4	2,1	3,4	2,3
Peas / beans, dry weight (legumes) ! D	0,5	0,4	0,4	0,6	0,3	0,5	0,4	0,5	0,4	0,6	0,4	0,5	0,4	0,5	0,4	0,5	0,4	0,5	0,4
Fruit and berries	41,7	42,7	42,2	36,9	36,2	43,6	47,7	38,9	41,2	42,1	44,3	45,0	43,1	41,2	41,2	45,3	42,1	34,3	49,1
fruit, berries, fresh	17,4	20,5	18,9	13,6	15,8	13,8	19,3	15,8	19,3	18,5	22,2	22,3	25,2	16,6	18,5	20,2	22,3	13,6	23,4
... Citrus fruits	2,9	3,4	3,2	2,3	2,6	2,3	3,2	2,6	3,2	3,1	3,7	3,7	4,2	2,8	3,1	3,4	3,7	2,3	3,9
...Bananas	4,1	4,9	4,5	3,2	3,8	3,3	4,6	3,8	4,6	4,4	5,3	5,3	6,0	3,9	4,4	4,8	5,3	3,2	5,6
... Apples	2,5	2,9	2,7	1,9	2,3	2,0	2,8	2,3	2,8	2,7	3,2	3,2	3,6	2,4	2,7	2,9	3,2	1,9	3,4
... Pears	0,3	0,3	0,3	0,2	0,3	0,2	0,3	0,3	0,3	0,3	0,4	0,4	0,4	0,3	0,3	0,3	0,4	0,2	0,4
... Stone fruits	0,5	0,5	0,5	0,4	0,4	0,4	0,5	0,4	0,5	0,5	0,6	0,6	0,7	0,4	0,5	0,5	0,6	0,4	0,6
... Berries	3,6	4,2	3,9	2,8	3,3	2,8	4,0	3,3	4,0	3,8	4,6	4,6	5,2	3,4	3,8	4,2	4,6	2,8	4,8
... Other fresh fruits	3,5	4,2	3,9	2,8	3,2	2,8	3,9	3,2	3,9	3,8	4,5	4,5	5,2	3,4	3,8	4,1	4,6	2,8	4,8
Jam, preserved fruits	5,9	4,4	5,2	4,6	3,4	4,7	4,2	5,4	4,2	6,3	4,8	7,6	5,5	5,6	4,0	6,9	4,8	4,6	5,1
nuts, olives, seeds	2,0	2,4	2,2	1,6	1,8	1,6	2,2	1,9	2,2	2,2	2,6	2,6	2,9	1,9	2,1	2,4	2,6	1,6	2,7

4.1.1.2. Most impacting food groups

The two most carbon intensive food groups are first ‘cheese’ with an intensity of 9 kg CO_2-e / kg of cheese and then ‘meat and meat products’ with an intensity of 6 kg CO_2-e/kg of meat.

The two least carbon intensive food groups are first ‘potatoes’ with an intensity of 0.3 kg CO_2-e/kg of potatoes and ‘fruit and berries’ with an intensity of 0.4 kg CO_2-e/kg of product

In beverages, ‘wine’ and ‘liquor’ are actually as intensive as meat as they both present a carbon intensity of 6 kg CO_2-e/ kg of product.

However in a diet the most and least carbon *intensive* food categories might not be the most and least *impacting* consumption categories as the overall footprint also depends on the amount of food consumed in each category. This way, for the average Norwegian diet, the two most impacting food groups are first ‘meat and meat products’ with 331 kg CO_2-e/ year (27% of total impacts) and second ‘milk and yoghurt’ with 175 kg CO_2-e/ year (14% of total impacts). Following these come ‘cheese’ with 152 kg CO_2-e/ year and ‘wine’ with 98 kg CO_2-e/ year.

4.1.1.3. Most impacting social groups

Men between 18 and 29 years old and men between 30 and 39 years old are the two most impacting social group. They are however the two social groups consuming the most calories, so such a ranking in terms of carbon footprint is not surprising.

The least impacting social groups are women between 60 and 70 years old and women without kids. Women in their 60’s are also the group consuming the least calories, but this does not hold for women without kids, as women between 18 and 29 years old are the second least calorie consuming group. The difference can then be explained by eating habits: women without kids and women in their 60’s are the two groups eating the less calories form ‘meat and meat products’ and ‘cheese’, which are the two most intensive food groups.

4.1.2 Food waste carbon footprint assessment

After including food wastes in the diet, 30 kg of food per year and 6.5 kg of beverages were added to the Norwegian average diet. These correspond to an additional impact of 114 kg CO_2-e/ year/ person. Given Norway's population in January 2015, food wastes amount to 190 kt of food and beverages per year, resulting in 588 kt CO_2-e indirectly emitted.

This increase in amount of food does not result in a linear increase in CO_2 release. Although food wastage increases the total food volume by 4%, it increases the related carbon emissions by 9%. This is explained by the fact that meat products, fish products and dairy products are not only the most carbon intensive food categories, but also some of the most wasted ones. Cereals, such as bread, is the single most wasted product category according to the percentages given by FAO. However, this is not of such impact in terms of carbon release as bread has a low carbon intensity (0.99 kg CO_2-e / kg product) compared to meat (6.13 kg CO_2-e / kg product) or cheese (9.5 kg CO_2-e / kg product).

4.1.3 Food supply carbon footprint assessment

Norwegian households' food supply activities lead each year to emissions of 1.07 MtCO_2-e. In comparison, Norwegian household's food consumption lead to 6.4 Mt CO_2-e as presented in section 4.1.1.

The most impacting process of the system is the use of conventional cars to shop for food, emitting 954 kt CO_2-e. The second most impacting process is the use of separate freezers with 48 kt CO_2-e emitted each year. The first process is thus about 19 times more impacting than the second one. The use of electric stoves and ovens comes third with emissions of 28 kt CO_2-e.

The least impacting process is the use of microwaves, which emits 318 t CO_2-e each year. The second least impacting process is the use of electric cars to shop for food, emitting 586 t CO_2-e. A big difference is observed between the least impacting process and the second least impacting one, as the use of electric cars by all Norwegian households has less than half of the direct emissions than the use of microwaves. The use of gas stoves and ovens is the third least impacting process with emissions of 2 kt CO_2-e per year.

The most impacting process of the system emits 2 995 times more than the least impacting one.

Both types of fridge are the processes with median emissions. A fridge with an integrated freezer is unsurprisingly more impacting (26 kt CO_2-e) than a fridge without (16 kt CO_2-e) since it has a higher ownership share and a higher electricity consumption.

From the Food Supply system, an average household carries embodied emissions of 447 kg CO_2-e / year, which also amounts to 203 kg CO_2-e/ pers / year.

4.1.3.2. Sensitivity analysis

The first parameter tested was the distance driven by car. Results showed a high response of the system to this parameter. After increasing the distance by 10%, overall impacts increased by 8.8 %, showing substantially strong correlation between this parameter and the system's performance.

The second parameter tested was the choice of background process in ecoinvent 22 to represent electricity use. Changing this parameter from 'Norwegian electricity/ low voltage/ at grid' to the 'Nordic electricity mix' decreased overall impacts by 3%. The uncertainty behind the ecoinvent process is thus not particularly worrying for the reliability of the results.

The ownership percentage of gas stoves and ovens was thirdly tested. A 0.05% reduction in overall impacts is observed after lowering the ownership percentage by three percentage points, from 4 to 1%. Here too the system's environmental performance seems to be little dependent on this parameter.

4.2. Reduction scenarios potentials

4.2.1. Diet scenarios potentials

The most effective scenario is scenario 4 – *veganism*. Compared to the baseline, it allows for a reduction of impacts of 39%. This diet leads to emission reduction of 1.3 kg CO_2-e per day, which is equal to 40 kg CO_2-e per month and 479 kg CO_2-e per year.

The least effective scenario is scenario 6 – *decreased dairy intake*. It leads to a reduction of impacts of 9%, which amounts to a reduction of 0.3 kg CO_2-e per year, 9 kg CO_2-e per month and 110 kg CO_2-e per year.

Scenarios 2 and 3 – *pescetarianism* and *vegetarianism* – show very similar results. Both lead to impact reductions of 17%. Pescetarianism is a slightly more efficient scenario than vegetarianism, as the former leads to emissions of 1010 kg CO_2-e a year while the latter leads to emissions of 1011 kg CO_2-e a year.

Scenarios 1 and 5 – *2300 kcal* and *meat-free dinners* – have comparable results to scenarios 2 and 3. Scenario 1 gives a 16% impact reduction while scenario 5 gives a 15% impact reduction.

Scenarios 1, 2, 3 and 5 – respectively *2300 kcal*, *pescetarianism*, *vegetarianism* and *vegetarian dinners* – all show impact reductions comprised between 15 and 17%. Figure 5 displays each scenario's carbon footprint and thus helps visualizing the different associated reduction potentials.

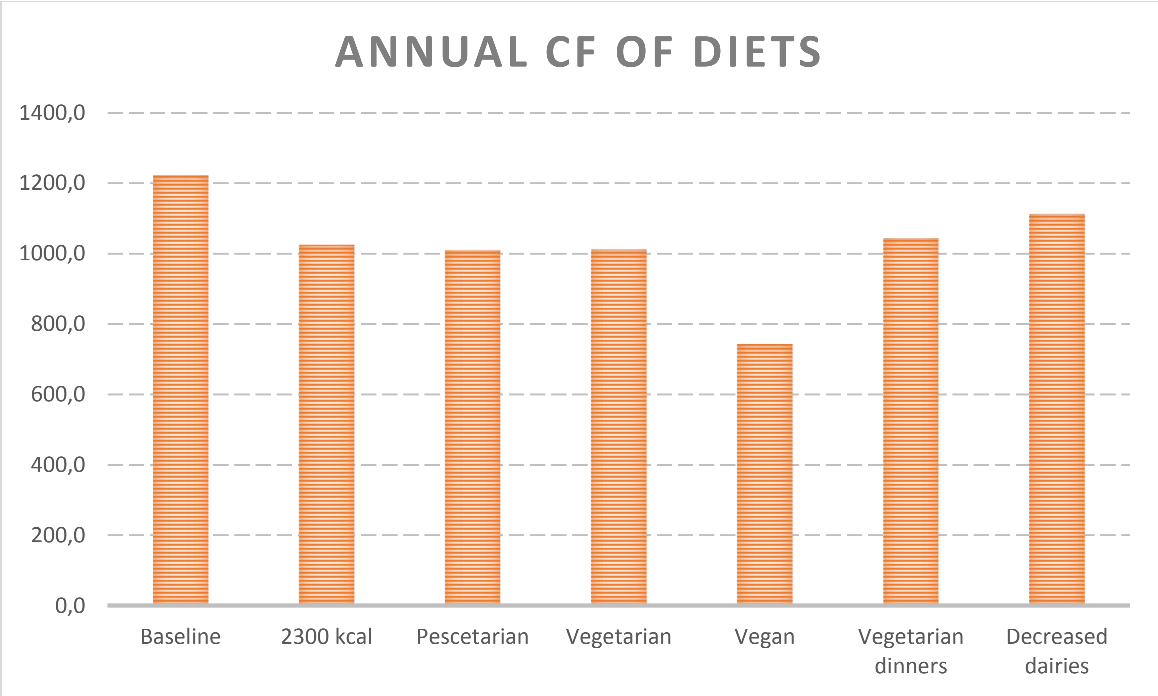

Figure 5: Overview of the annual performances of the different diet scenarios

Table 7 ranks the scenarios according to their reduction potential from the baseline, from the most to the least effective scenario in terms of emission reduction.

Table 7: Ranking of impact reductions from every diet scenarios

Scenario	Annual emissions in kg CO2-e	Impact reduction in kg CO2-e	Impact reduction in percentage
0- Baseline	1223	-	-
4- Veganism	744	479	-39%
2- Pescaterianism	1010	213	-17%
3- Vegetarianism	1011	211	-17%
1- 2300 kcal	1025	197	-16%
5- Meat-free dinners	1043	180	-15%
6- Decreased dairy intake	1113	110	-9%

4.2.2. Food supply scenarios potential

Out of the seven scenarios assessed, the one showing the least carbon impacts was scenario G, which represents a household using an electric car and not owning a separate freezer. Such a household emits 70 kg CO_2-e per year. The scenario having the most impacts was scenario A, which represents a household owning a gas stove/oven and a conventional car and which has a total impact of 414 kg CO_2-e per year.

The scenarios' results show that the most effective way to reduce one household's emissions is to shift from taking grocery trips with a conventional car to an electric car.

Table 9 shows a ranking of the scenarios by their carbon footprint, the top scenarios being the least impacting and the bottom scenario the most impacting.

The clear pattern coming out of the comparison table 7 is that the type of vehicle used is determinant for a household's food supply impacts. Afterwards both scenarios that assume a household without a separate freezer (scenarios G and D) perform the best for their respective type of vehicle.

There is a difference of 344 kg CO_2-e a year between the best performing scenario (G) and the least (A). This means that, one on the food supply system, the most carbon efficient household emits about 6 times less that the least efficient.

Among households having a conventional car, even the most efficient household (D) is about 4 times worse in terms of carbon emissions from food supply than the least efficient household having an electrical vehicle (E).

All things being equal, a household using an electrical vehicle for grocery shopping (F) saves 307 kg CO_2-e per year compared to a household using a conventional car (C).

Table 8: Ranking of food supply scenarios

Carbon efficiency ranking	Scenario	Impacts in kg CO2-e/yr	Gas stove/ oven	Electric stove/ oven	Microwave	Fridge w/o freezer	Fridge w/ freezer	Separate freezer	Electric car	Conventional car
1	G	70		x	x		x		x	
2	F	95		X	x	x		x	x	
3	E	98		X	x		x	x	x	
4	D	377		X	x		x			x
5	C	402		X	x	x		x		x
6	B	405		X	x		x	x		x
7	A	414	x		x		x	x		x

5. Discussion

5.1. Reliability of the results

5.1.1 Uncertainties and assumptions

5.1.1.1. Arising from the carbon footprint of the current diet

The model contains a significant number of assumptions. Thirty food items out of a hundred (30%) had assumed carbon intensities for lack of finding consistent data in the literature. Thus, a third of the food items carbon intensities are assumed. Ninety percent of these assumptions are based on literature, that is to say assumed similar to other food items intensities found in literature. Ten percent of the assumptions are informed guesses, which represent 3% of the total data.

Moreover, seven food items intensities are gathered from EPDs. Any carbon intensity found in an EPD is specific to a brand and a product. Thus, it does not well represent a food product in general and might lead to an overestimation or an underestimation of this product's carbon intensity.

The remaining 63 carbon intensities were taken from existing literature. Twenty-nine of them are based on Wallén et al. (2004).

The above mentioned assumptions account for the largest part of the uncertainties that lie in the model. The multiple sources of data is also an issue as it brings inconsistence in methods and system boundaries among the carbon intensities. Thus a direct comparison of these intensities, as assumed here, is not always valid.

In the matter of misleading comparison, 'cream and cream products' have a surprisingly low carbon intensity when compared to other dairy products. Indeed, beef products and milk intensities were taken from the same source, which uses an economic allocation (for a definition of economic allocation see Strømann 2010). However 'cream products' were assigned the intensity given by Wallén et al. (2004). This paper does not indicate an allocation method nor an accessible source. There is thus an uncertainty around the intensity of 'cream and cream products'. However as the amount consumed per person is low in a diet, this should not significantly influence the results.

Furthermore, the age of the carbon intensities data brings another layer of uncertainty. As stated previously, almost a third of the food items intensities were taken from Wallén et al. (2004), which is a 10 years old paper. Current production methods might incur different amounts of CO_2-e depending on the type of food produced. Current carbon intensities might therefore be slightly different from the ones found by Wallén et al. in 2004.

As opposite to carbon intensities, all calorie intensities were taken from one source, which makes their direct comparison valid.

5.1.1.2. Arising from food waste carbon footprinting

Food wastage is still a largely unexplored area and numbers on it are scarce. It was necessary to complete the lack of data with conservative assumptions for the majority of the food categories. There is thus a high uncertainty linked to food waste in the present work. Indeed, the model resulted in an increase of 4% of the intakes in grams, whereas other experts talk about a household’s waste fraction of nearly 42% of the global food wastes in the EU (Gustavsson et al., 2011). Gjerris and Gaiani (2013) gave an estimation of an annual food waste of 51 kg per person in Norway. The fact that the results presented here are lower compared to both sources indicates a probable underestimation of the food wastage from the model. It is unsure how significant the underestimation of food wastage is here, but it is likely to be high.

5.1.1.3. Arising from food supply activities carbon footprinting

Data on appliances’ electricity consumption and ownership were taken from a technical report from SINTEF published in 2010 (Hanne et al., 2010). Data on the total number of households in Norway is taken from national statistics (SSB Table 6077) and data on car trips was taken from a paper written in 2005 (Sonesson, Anteson, et al., 2005).

Data used to build the matrices are between 5 and 10 years old. They might thus misrepresent the current level of related activities. To better understand how affected the system might be by the assumptions made, a sensitivity analysis was carried out for the most critical data, presented in section 4.1.3. The sensitivity analysis shows an almost linear correlation between the distance driven by car and the CO_2 emissions arising from food supply activities. This implies a significant uncertainty in the model, since data on the actual distance driven for groceries specifically in Norway is unknown and assumed from a ten years old Swedish survey. This data, which discloses distances from trips with the sole purpose of shopping for food, most likely underestimate the actual distance driven in relation with food shopping. Thus, overall impacts from the model are likely to be underestimated with the same proportion.

Another weakness of the model is its inflexibility in terms of frequency of use of the different appliances. As it is now, the model gives an idea of the impacts arising from households' choices (appliances and type of car) but does not allow to compare households' habits. Households can have different cooking practices that would be interesting to assess in terms of environmental impacts, such as preferring to cook food in the oven rather than from the stove, cooking large amounts of food and then freezing it rather than cooking every day, etc. Data about average cooking habits per households is still missing to implement changes in the model enabling such a break-down; such data and its correlation to different types of diets would open up for an interesting analysis.

5.1.1.4. Arising from diet scenarios

The construction of each scenario was mainly based on dietary recommendations and/or on observations from the carbon footprint of current average Norwegian diets. It was necessary to also compose diet scenarios based on assumptions. In particular, assumptions were made on how food groups can replace each other. For example in scenario 4 – *veganism* – the increase of vegetable intake is three times greater than the increase of grain products intake. That was based on the fact that the 'vegetables' category contains peas, beans and legumes, which are assumed to be main ingredients in a vegan diet. This shortcoming might misrepresent the actual average vegan diet, thus causing misleading results of the associated carbon footprint. This would however not be significant given the fact that grain products have a carbon intensity of 0.1 kg CO_2-e greater than the one of vegetables (1.1 vs 1.0 kg CO_2-e/kg product).

In scenario 5 – *vegetarian dinners* – an increase in bread was assumed, whereas this is not the case in scenario 3 – *vegetarianism*. It would have however been more consistent to increase the same food categories between these two scenarios, and would have enhanced their comparability.

5.1.2 Agreement with literature

Crossing the second chapter of this work (literature review) with the fourth (results), the analysis presented here finds similar results than found in previous literature regarding food consumption. In particular, the importance of animal products consumption is underlined in all researches. Results of the current average Norwegian diet' carbon footprint of 1233 kg CO_2-e per year accurately match the results form Steen-Olsen et al (submitted), who conducted their analysis with a top-down approach, for Norway.

However, the present work finds different shares of emissions regarding food supply. The analysis found that food transportation from the supermarket to the home is by far the main contributor to the total food supply carbon footprint. This disagree with findings of Kauppinen et al. (2010), which support the point that food preservation is the most impacting process. The difference between the two analyses might come from Finland's electricity mix, which is mainly dependent on fossil fuels (OECD/IEA, 2012). It might also come from different food related habits in the two countries, notably in terms of food planning and shopping (for more information, see Kauppinen et al. 2010). The disagreement of the two papers might also come from uncertainties lying in the model presented in section 5.1.1.

5.2. Further implication of this work

5.2.1. Policy suggestions

5.2.1.1. Tackling food waste

Food waste raises important environmental and ethical issues. As shown by the present work, it would be possible for Norway to save annually 581 kt of CO_2-e solely by eliminating food waste at the consumer stage. Such an objective is not realistic, but this number gives a hint on how important improvement in the domain of food wastage can be.

As seen in the results, increase in food volume due to food waste and increase in related carbon footprint are not linear due to the nature of the food products thrown away the most. As such, actions taken to raise consumers' awareness should especially target these critical food items that are 'meat and meat products', 'milk and yoghurt' and 'cheese'. Vegetables are the second most wasted product category, but accounts for less than 5% of the impacts associated to a diet with food wastes.

In its report on food wastes in Norway, the Norwegian research institute Østfoldforskning indicates that the main reason for consumers to throw food away was that food was "past its expiry date" (Hanssen & Møller, 2013). In parallel, Gjerris & Gaiani (2013) indicate that "75% of total purchases in the Nordic food shops are decided after arrival at the shop". Linking these two information, it would be beneficial to encourage better planning among consumers.

Gjerris & Gaiani (2013) explain that devaluation of food and loss of social and emotional linkage to food are social phenomenon that could at least partly explain the increase of food wastage in the last decades. Campaigns could be taken in the attempt to establish a better emotional link between consumers and their food. Such link could be easily emphasized on animal products (meat, dairies) and thus target more specifically the most significant food categories in terms of food wastes.

A set of actions are also possible to indirectly help people reducing food wastes, such as reducing packaging size to better suit small households' needs, or have packaging with easy opening and closing mechanisms for better storage, like suggested by

Gjerris & Gaiani (2013). A technique called “nudging” aims at influencing consumer’s behavior by changing “any aspect of the choice architecture that alters people’s behavior in a predictable way without forbidding any options or significantly changing their economic incentives” (Thaler and Sunstein, 2008). Kallbekken & Sælen (2013) tested the technique to tackle food waste in hotels, and showed that reducing plates’ size lead to a decrease in wasted food.

An encouraging result from the Østfoldforskning document is that food wastage in households seem to be already declining (Hanssen & Møller, 2013). Furthermore, the ForMat project put an emphasis on eggs and sour cream wastes, the food items that are showing the most decrease in frequency of discarding food (Hanssen & Møller, 2013). This is also encouraging to prove that communication campaign have received attention and people are receptive to it.

5.2.1.2. Tackling food supply activities

Results from the LCA on food supply activities and its scenarios show that food-shopping trips with a conventional car is by far more impacting than the use of kitchen appliances. This results encourage further current political efforts in enhancing electric cars ownership in Norway.

5.2.1.3. Tackling diets

Results show that scenario 4 – *Veganism* – has the greatest reduction potential out of the 6 scenarios. Four other scenarios – *2300 kcal, pescetarianism, vegetarianism and vegetarian dinners* – show similar reduction potentials. Popularizing such diets is desirable in order to reduce food consumption related carbon emissions. Such a target however encounters several impediments, which will now be introduced, along with possible solutions.

A first disincentive of changing diet may be the intricacy of the alternative diet. According to Girod et al. (2014), the complexity of products is one of the four main obstacles facing low greenhouse gas consumption options. Complexity is “determined by the skills necessary to find and adopt a certain consumption option” (Girod et al., 2014). Craig (2009) raises the fact that, except if consumption is thoroughly followed or appropriate complements are taken, nutrient shortfalls are of concern for a vegan's health; Dwyer (1988) raises the same issue for vegetarian diets. In this way, knowledge and effort are prerequisites to closely follow up on one's nutrients intake. Shifting from an average Norwegian diet to a vegan or vegetarian diet might thus require effort to bypass the mental barrier raised by the complexity of such a change.

A first step would be a campaign valorizing veganism and different patterns of vegetarianism in terms of health, environment and ease. Such a campaign should deconstruct the image of difficult life changes carried by alternative diets. Making it easier to follow a vegan or vegetarian diet would be a second step. Examples of such actions include greater vegan and vegetarian options in cantinas, dedicating a shelf for vegan food and complements in supermarkets, and creating recipe guidelines for vegetarians and vegans. The nudging technique can also be efficient to encourage people to change their eating habits, as shown by Hanks et al. (2012).

Consumer preferences, as identified by Girod et al. (2014), are a second disincentive to changing diets.

Scenarios results are encouraging in addressing that second barrier. The fact that four diets have similar carbon footprints supports consumer's freedom to choose according to their preferences. A person who is reluctant to change his or her diet because of certain tastes, but who is still willing to reduce his or her food-related carbon footprint, will most likely find a diet among the four that suits his or her tastes. For instance, a person who is averse to giving up meat has the choice to reduce his or her total calorie intake to match a 2300 kcal diet - 2000 kcal/day if the person is a woman, 2600 kcal/day if the person is a man – and obtain a similar carbon footprint than vegetarians. Another solution would be to adopt a diet with vegetarian dinners. Additionally, a person who opposes vegetarianism because of his or her taste for fish can be encouraged to adopt a pescetarian diet instead.

Several studies agree that sustainable diets align with healthy diets, as presented in the second chapter of this work. Modifying Norwegian consumption habits can reduce overweight and certain diseases. According to the Norwegian Institute of Public Health, about a half of male adults in Norway are overweight, out of which between 15 and 18% are considered obese (Norwegian Institute of Public Health 2015). Moreover, meat consumption is correlated with several health drawbacks, such as increased incidence of coronary heart disease, colorectal cancer and diabetes (Chao et al., 2005; Cross et al., 2007; Dwyer, 1988; McAfee et al., 2010).

Government actions promoting sustainable diets lead to common goals with the ones tackling the health issues mentioned above. The 2300 kcal diet promotes eating amounts corresponding to actual physical and metabolic needs, thus helping reduce the number of overweight people. Scenarios that partly or entirely exclude meat consumption indirectly support government actions tackling the meat-associated disease. This mutual support shows the coherence of bringing together health-promoting campaigns with sustainability ones in terms of objectives, which could also make sense in budgetary terms, as common campaigns could lower the total cost of each separate ones.

Taxing meat in order to increase meat and meat products prices would be an interesting policy to investigate further. It could directly lead to a purchase decrease, thus nudging consumers to buy, and by consequence eat, less meat. It could also indirectly counteract the phenomenon of devaluation and lead to a decrease of food waste, as mentioned in section 5.1.3 above. To compensate a possible negative rebound effect of such a tax on farmers, the benefits could be used to increase farmers' subsides. Similar taxation strategies could be applied to dairy products and progressively to other animal products.

5.2.2. Further research

The level of uncertainty comprised in the model weakens the reliability of the results. This is the reason for which further research should aim at producing data more specific for the Norwegian context, and at completing gaps in existing data.

Another significant drawback of this study is its incapacity to show or predict problem shifting issues. Before drawing any conclusions based on this work, it is important to bear in mind that results only show the carbon impacts of the system. When it comes to food production, a number of other impact categories are also relevant to look at, such as water use, marine resource depletion, soil acidification and freshwater eutrophication. Dietary changes and policy suggestions discussed here might also lead to negative rebound effects such as decreasing employment in the meat industry. Further research is needed to evaluate such trade-offs. A more complete assessment of the benefits and hindrances of following diets recommended in this work is needed before implementing changes.

6. Conclusion

The present work aimed at assessing the average carbon footprint of Norwegian diets and at investigating associated reduction potentials. It was found that, for an average Norwegian, food consumed at home carries embodied emissions 1.2 t CO_2-e per year per person. Men have a carbon footprint around 1.3 times higher than women due to their greater intake of calories per day. It was also found that ‘cheese’ and ‘ meat and meat products’ are the two most carbon intensive food groups, while ‘potatoes’ and ‘fruits and berries’ are the two least. Due to the amounts consumed per day, most impacts of an average diet come from ‘meat and meat products’ and ‘milk and yoghurt’. On average, activities related to food transport, storage and preparation have a carbon footprint of 447 kg CO_2-e per household and per year, equivalent to 203 kg CO_2-e per person. Food wastes correspond on average to an impact of 114 kg CO_2-e per person per year.

In total, an average Norwegian person has a carbon footprint of 1547 kg CO_2-e for food transported to the home, stored, prepared, thrown away and/or consumed.

Scenarios to assess reduction potentials showed benefits of lowering total calories intakes as well as animal products consumption. The least carbon intensive diet assessed here is veganism, followed by pescetarianism and vegetarianism. The two latter diets showed results similar to a diet of 2300 kcal per day and a diet based on vegetarian dinners.

Associated policy recommendations are campaigns to promote veganism and reduction of animal products consumption. Nudging can be used to tackle both food wastes and animal products consumption. A tax on animal products is another form of incentive to be considered. Such policies can be aligned with health concerns. The main barriers of their achievement are consumer preferences and the complexity of following non-mainstream diets.

When reading the conclusions of this work, one must bear in mind two of its limitations that are important to consider. One is that uncertainties are associated to the results, and the other is that those results are exclusively focused on carbon footprint. A set of other environmental, social and economic impacts should be taken into consideration to give a more complete picture of the current situation and its preferable developments. Further research in the domain of Norwegian food consumption and its desirable trends should focus on improving existing data for the Norwegian context, and assessing potential trade-offs.

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Tables from National Statistics

Tables' number:

- 6077
- 05810
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All tables are available from www.ssb.no/statistikkbanken

Environmental Product Declarations

EPDs' number:

- S-P-00128
- S-P-00232
- S-P-00237
- S-P-00325
- S-P-00326
- S-P-00492
- S-P-00679

All EPDs are available from environdec.com

Appendices

Appendix A – Foreground of Scenario A

In this Sheet, you enter your foregronk), and your foreground requirement matrix (A_ff, oran

	Label (PRO_f):		**y_f:**		**A_ff:**	*1*	*2*	*3*	*4*	*5*
	FULL NAME	**PROCESS ID**				**Food sup**	**Food pre**	**Food sto**	**Food trai**	**Gas stov**
1	Food supply	10001		1						
2	Food preparation	10002				1				
3	Food storage	10003				1				
4	Food transportation	10004				1				
5	Gas stove/ oven	10005					1			
6	Electric stove / oven	10006					0			
7	Microwave	10007					1			
8	Fridge w/o freezer	10008						0		
9	Fridge w/ freezer	10009						1		
10	Freezer	10010						1		
11	Electrical car	10011							0	
12	Conventional car	10012							1	

Appendix B – Foreground of Scenario B

In this Sheet, you enter your foregronk), and your foreground requirement matrix (A_ff, orange)											
	Label (PRO_f):		y_f:		A_ff:	1	2	3	4	5	6
	FULL NAME	PROCESS ID				Food sup	Food pre	Food sto	Food tra	Gas stov	Electric s
1	Food supply	10001		1							
2	Food preparation	10002				1					
3	Food storage	10003				1					
4	Food transportation	10004				1					
5	Gas stove/ oven	10005					0				
6	Electric stove / oven	10006					1				
7	Microwave	10007					1				
8	Fridge w/o freezer	10008						0			
9	Fridge w/ freezer	10009						1			
10	Freezer	10010						1			
11	Electrical car	10011							0		
12	Conventional car	10012							1		

Appendix C – Foreground of Scenario C

In this Sheet, you enter your foregro			***nk), and your foreground requirement matrix (A_ff, orange)***								
	Label (PRO_f):		**y_f:**		**A_ff:**	*1*	*2*	*3*	*4*	*5*	*6*
	FULL NAME	**PROCESS ID**				**Food sup**	**Food pre**	**Food sto**	**Food tra**	**Gas stov**	**Electric s**
1	Food supply	10001		1							
2	Food preparation	10002				1					
3	Food storage	10003				1					
4	Food transportation	10004				1					
5	Gas stove/ oven	10005					0				
6	Electric stove / oven	10006					1				
7	Microwave	10007					1				
8	Fridge w/o freezer	10008						1			
9	Fridge w/ freezer	10009						0			
10	Freezer	10010						1			
11	Electrical car	10011							0		
12	Conventional car	10012							1		

Appendix D – Foreground of Scenario D

In this Sheet, you enter your foregronk), and your foreground requirement matrix (A_ff, orange)												
	Label (PRO_f):		**y_f:**		**A_ff:**	*1*	*2*	*3*	*4*	*5*	*6*	
	FULL NAME	**PROCESS ID**				**Food sup**	**Food pre**	**Food sto**	**Food tra**	**Gas stov**	**Electric s**	
1	Food supply	10001		1								
2	Food preparation	10002				1						
3	Food storage	10003				1						
4	Food transportation	10004				1						
5	Gas stove/ oven	10005					0					
6	Electric stove / oven	10006					1					
7	Microwave	10007					1					
8	Fridge w/o freezer	10008						0				
9	Fridge w/ freezer	10009						1				
10	Freezer	10010						0				
11	Electrical car	10011							0			
12	Conventional car	10012							1			

Appendix E – Foreground of Scenario E

In this Sheet, you enter your foregronk), and your foreground requirement matrix (A_ff, orange)

	Label (PRO_f):		y_f:		A_ff:	1	2	3	4	5	6
	FULL NAME	**PROCESS ID**				**Food sup**	**Food pre**	**Food sto**	**Food trai**	**Gas stov**	**Electric s**
1	Food supply	10001		1							
2	Food preparation	10002				1					
3	Food storage	10003				1					
4	Food transportation	10004				1					
5	Gas stove/ oven	10005					0				
6	Electric stove / oven	10006					1				
7	Microwave	10007					1				
8	Fridge w/o freezer	10008						0			
9	Fridge w/ freezer	10009						1			
10	Freezer	10010						1			
11	Electrical car	10011							1		
12	Conventional car	10012							0		

Appendix F – Foreground of Scenario F

In this Sheet, you enter your foregronk), and your foreground requirement matrix (A_ff, orange)											
	Label (PRO_f):		**y_f:**		**A_ff:**	*1*	*2*	*3*	*4*	*5*	*6*
	FULL NAME	**PROCESS ID**				**Food sup**	**Food pre**	**Food sto**	**Food tra**	**Gas stov**	**Electric s**
1	Food supply	10001		1							
2	Food preparation	10002				1					
3	Food storage	10003				1					
4	Food transportation	10004				1					
5	Gas stove/ oven	10005					0				
6	Electric stove / oven	10006					1				
7	Microwave	10007					1				
8	Fridge w/o freezer	10008						1			
9	Fridge w/ freezer	10009						0			
10	Freezer	10010						1			
11	Electrical car	10011							1		
12	Conventional car	10012							0		

Appendix G – Foreground of Scenario G

In this Sheet, you enter your foregronk), and your foreground requirement matrix (A_ff, orange)											
	Label (PRO_f):		**y_f:**		**A_ff:**	*1*	*2*	*3*	*4*	*5*	*6*
	FULL NAME	**PROCESS ID**				**Food sup**	**Food pre**	**Food sto**	**Food tra**	**Gas stov**	**Electric s**
1	Food supply	10001		1							
2	Food preparation	10002				1					
3	Food storage	10003				1					
4	Food transportation	10004				1					
5	Gas stove/ oven	10005					0				
6	Electric stove / oven	10006					1				
7	Microwave	10007					1				
8	Fridge w/o freezer	10008						0			
9	Fridge w/ freezer	10009						1			
10	Freezer	10010						0			
11	Electrical car	10011							1		
12	Conventional car	10012							0		