The carbon footprint of rye bread production in Sweden

- *A life cycle assessment (LCA) of the Fazer product Rågkusar*

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Abstract

The future will require sustainable food systems; systems that meets the present and the future with consideration of economic and social development, as well as environmental protection. In the current food system, two key drivers towards environmental pressure are agriculture and food consumption. Life Cycle Assessment (LCA) is a useful method for assessing the environmental impact of food products. In current study, the rye bread Rågkusar by Fazer is assessed by conducting an LCA. The aims for the study have been to find the carbon footprint of Rågkusar, its climate hotspots and to find improvement possibilities throughout the life cycles. By mapping out the product system and assessing Rågkusar in the scope of *from cradle to retail*, the carbon footprint found was 0.37 kg CO_2e per kg bread. The main climate hotspot found were the ingredients of the bread. By performing sensitivity analysis some potential improvements that would lower the climate impact of Rågkusar are presented, e.g., use more organic grains (due to lower use of fertilizers and pesticide), reduce their side streams, and change to electric trucks and biofuel trucks for transportations. The findings in current study were to some extent in line with previous research. However, the carbon footprint is rather low compared to what prior studies has observed. There are several possibilities for this which is further discussed in the study. The possible improvements for Rågkusar were presented to Fazer and this study presents the comments from Fazer about these improvements. LCAs are partly based on assumptions, which is seen as a limitation for this study, the use phase was excluded from the system boundaries, this is another limitation. Future studies are recommended to expand the system boundaries, or to analyse several environmental impacts related to the bread production.

Keywords: Life Cycle Assessment (LCA), Bread, Rye bread, Bread production, Sustainable development, Carbon footprint, Global warming potential

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Abbreviations

CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalents
FU	Functional unit
GHG	Greenhouse gases
GWP	Global warming potential
HVO	Hydrotreated vegetable oil
ISO	International Organization for Standardization
LCA	Life cycle assessment
LDPE	Low density polyethylene
N_2O	Nitrous oxide
RME	Rapeseed methyl esters
TBA	Take-bake agreement

1. Introduction

The world as we know it today is rapidly changing. We are currently facing an increasing food demand due to population growth and economic development, alongside the continuing climate changes. Meeting these demands without risking crossing the planetary boundaries demonstrates a challenge (Steffen et al., 2015a; Godfray et al., 2010), requiring food systems that does not impose on the Earth's resources (Steffen et al., 2015b). This emphasizes the importance of sustainable food systems, meaning a system that meets the present and future needs, with consideration of economic development, social development, and environmental protection (EU, 2014).

Our current food system is a key driver of environmental pressure e.g., for habitat change, climate change and toxic emissions. Hence, greenhouse gas (GHG) emissions, which there are a few types of, such as carbon dioxide, methane, and nitrous oxide. The fossil emissions account for the majority of all GHG emissions (UNEP, 2010). GHG emissions exist in the atmosphere and are emitted both by natural processes and human activities. However, human-driven emissions intervene with the natural processes and cause climate change by trapping heat in the atmosphere (Steffen et al., 2015b).

Agriculture has shown to have a large contribution to GHG emissions (UNEP, 2010). A typical agricultural good is bread, which is seen as a staple food in many parts of the world, to be eaten with meals or as a snack. Bread can contain different types of ingredients, sometimes imported from various places in the world. The more diversified ingredients, the more difficult it is to assess its environmental impact (Notarnicola et al., 2017).

Complex food systems require a holistic approach towards becoming more sustainable, with life cycle thinking being a useful tool for it (Sala et al. 2015). Life cycle assessment (LCA) is an increasingly used method for evaluating the environmental impact of a product, process, or activity. With LCA, it is possible to calculate the environmental impact from the first to the last phase, or of a phase in between. The concept was developed in the 1960s and has since then evolved and today it has an overall framework for usage (Roy et al., 2009; Golsteijn, 2020). The purpose of an LCA can be to: compare alternative products, processes, or services; or compare various life cycles for a product or service; or identify parts where the most improvements can be made (ISO, 2006).

1.1 Literature review

The environmental impacts of bread have been studied in several previous LCAs, covering several focal areas, e.g., scale of production, waste, and scenario comparison (Brancoli et al., 2020; Brancoli et al., 2017; Braschkat et al., 2004). Furthermore, research has also been performed on specific types of bread e.g., wheat bread, whole grain bread, and rye bread (Jensen & Arlbjørn, 2014; Grönroos et al., 2006).

Andersson and Ohlsson (1999) studied the environmental impact of a wheat loaf by comparing four scales of bread production: larger industrial bakery, smaller industrial bakery, local bakery, and home baking. All life cycles of the production were included in the study. Their findings showed that bigger industrial bakeries had a higher energy consumption per 1 kg bread, which was the main cause of environmental impact. The smaller industrial bakery, local bakery and home baking had no significant difference in environmental effects. Their findings also indicated that home baking required a relatively high amount of energy per kg of bread and was therefore seen as less energy efficient. A more recent study by Notarnicola et al. (2017) analyzed the energy usage of 21 different types of breads to find and compare their environmental impact. They concluded that ingredients matter, thus breads with animal-based components, such as eggs, butter, milk etc., had a larger effect on the environment. This was mainly due to the energy required in the embedded animal-based ingredients. In contrast, breads with simpler ingredients, e.g., water, flour, and yeast were shown to be less energy requiring and therefore resulted in a lower environmental impact. Furthermore, the size and shape of bread showed to be of importance for energy usage, as it influenced the required baking time and its energy usage. Lastly, they found that the agricultural phase caused the largest environmental impact throughout the bread's life cycles, due to the use of pesticides and fertilizers. Goucher et al. (2017) have studied the environmental impact of wheat bread, their result indicated that more than half of the impact of production was linked to cultivation. Out of these, around 40% of the emissions were due to the use of fertilizer. In another study by Braschkat et al. (2004) multiple scenarios were designed for different kinds of bread production to compare its environmental impacts. Similarly, to Goucher et al. (2017) they also concluded that cultivation was the production phase that implied the largest global warming potential, followed by the baking as it was the most energy requiring process. From the scenarios they could establish that the ideal bread production used organically grown wheat, grinded through an industrial mill and baked in a larger bread factory. Their results showed that the more organic grains used, the better the environmental result. Except from land usage due to the need of bigger lands in organic cultivation (Braschkat et al., 2004).

Espinoza-Orias et al. (2011) compared different types of bread and found that whole grain bread generally had a lower carbon footprint as it utilised the wheat grain more efficiently. Another finding showed that the consumption phase was the second largest hotspot, due to assumptions of toasted and refrigerated bread. Although, they also found the main hotspot to be grain cultivation. In a latter study by Jensen and Arlbjørn (2014), the hotspots of rye bread production were discovered. The largest hotspot was cultivation, followed by processing because of its high usage of energy. In another study that assessed rye bread production the authors suggested that the production's energy source can lead to considerable differences in the products environmental impact (Grönroos et al., 2006).

In Sweden, bread waste has shown to be a large part of the total food waste in retail (Brancoli et al., 2020), it also has one of the highest environmental impacts amongst food waste (Brancoli et al., 2017). Depending on where the waste is directed towards, the environmental impact can differ greatly. E.g., if bread and packaging are separated and are directed towards recycling and animal feed, this could lower the environmental effect. Furthermore, some waste streams have a better utilization than others, with source reduction, donation, or production of feed, beer or bioethanol being favoured over anaerobic digestion and incineration (Brancoli et al., 2017). Choosing the preferred ones in productions etc. could lead to a reduced environmental impact (Brancoli et al., 2020).

1.2 Background

The commissioner of this study was Fazer Sweden AB (Fazer Group). The company was founded in Finland in 1891, today Fazer operates in eight countries and exports products to about 40 countries (Fazer, n.d.a). Fazer operates in the markets of baking, confectionary, non-dairy and plant-based products and is one of the largest food companies in the Nordics (Fazer, n.d.b).

Fazer’s bakeries represent about 20% of the Swedish market for pre-packaged bread, Rågkusar stands for 2.4% out of Fazer’s share. Which implies a yearly sale of 1181 ton/ 2.4 million packaged bread sold in the different packaging sizes, see figure 1 (Fazer, 2023a; AC Nielsen market analysis, 2022).

All Fazer’s breads are distributed under the take-bake agreement (TBA) existing in Sweden. A business model where the bakery companies are responsible for the forecasting, placement, and removal of bread from retail. The bread companies are financially responsible for the bread and will only be paid by retailers for the sold bread. The unsold breads are returned by the bakeries, resulting in a reverse supply chain (Ungerth, 2019). For Fazer, this means that they are responsible for production, delivery to external distribution center, and waste management for their production side streams.

1.3 Aim and objective

The interest for this study was to assess the carbon emissions of the production of Rågkusar, and to identify climate hotspots in the life cycle. The goals of the study are to identify:

- What is the carbon footprint of Rågkusar?
- Which are the life cycle phases with the highest contribution to the carbon footprint?
- Where are the improvement possibilities in the life cycle of Rågkusar?

Furthermore, the study aims to investigate the how changing certain processes in the life cycle could influence the products carbon footprint. Lastly, this study intends to provide result-based improvements for Fazer to implement into their sustainability work.

2. Scope of the study and functional unit

This study assessed the carbon footprint of the rye bread Rågkusar produced by Fazer, using life cycle assessment (LCA) as a method. The calculation has followed the ISO standards for LCA 14044 (2006) and 14067 (2018).

The product assessed in this study is Rågkusar (see figure 1). Rågkusar comes in two packaging sizes: six breads (338 g), and 12 breads (675 g).

Nutritional information / 100 g	
Energy	950 kJ / 230 kcal
Fat - of which saturated fats	1,9 g <0,5 g
Carbohydrates - of which sugars	41 g 2,1 g*
Nutritional fiber	11 g
Protein	6,7 g
Salt	1,2 g

*Contains natural sugars

Figure 1. Illustrating product (in smaller sized packaging) and its nutritional information (Fazer, n.d.c).

The functional unit was set to 1 kg of Rågkusar, including both production and processing of the bread and its packaging. None of the current packaging sizes represents 1 kg of bread, the assumed value for package materials has been based on the smaller package size (figure 1) since that size that has a larger distribution (Fazer, 2022a).

2.1 System boundaries and limitations

The life cycle phases *from cradle to retail* of the bread and its packaging were included in the system boundaries. Additionally, storage at retail and waste management of packaging was also included (packaging waste at retail). The packaging of the ingredients and packing materials were excluded. Also packaging materials that are reusable, e.g., pallets for transportation, have been excluded from the system boundaries. Animal feed production associated with bioethanol production was excluded from the study. The use phase and end of life of the product were outside the scope of this study as it is not controlled by the commissioner Fazer.

The system boundaries are illustrated in figure 2.

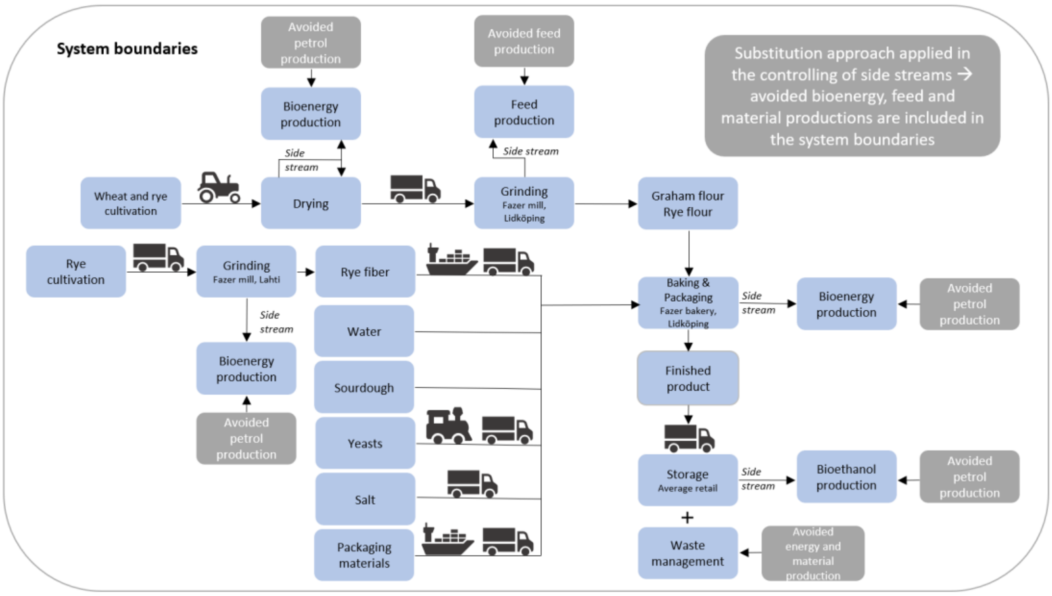


Figure 2. Figure showing the system boundaries of the study.

2.2 Allocation procedure

Current study has followed the allocation procedure of ISO 14044 (2006). The recommendation of ISO 14967 (2018) has also been considered. Hence, allocation has been avoided whenever possible, elsewhere, system expansion has been used. Meaning that by-products have been included in the system boundaries, assuming that these will replace another product by using a substitution approach. For example, if a side stream production is bioethanol, it can be assumed to replace petrol production (Balat & Balat, 2009). Meaning that the production of bioethanol was accounted for, although by assuming the replacement of petrol, the production of petrol is avoided.

Secondary datasets are used for various processes in this study, e.g., cultivation, transportations, and material production. These datasets include multifunctional processes, meaning, allocation has been included in these.

2.3 Data types and sources

Several types of data sources have been used in this study. A large part of the data was collected directly from Fazer mill and Fazer bakery in Lidköping, some data came from Fazer's supplier. The data was collected by email correspondence and a few semi-structured interviews. This data represents average production from annual data. Some of Fazer's suppliers have had a carbon footprint linked to their goods, which have been used in current study. This applies for e.g., the yeast ingredient. The data for the transportation of goods was collected from Fazer's suppliers whenever possible, some had information regarding truck capacity and distance. Others did not have the information and values therefore had to be assumed.

The secondary data for this study was collected for parts where Fazer were not in charge of the process. This being e.g., grain cultivation, energy- and water production and the manufacturing of materials. The secondary data in this study were collected from LCA databases such as Agri-footprint and Ecoinvent 3.9.1.

2.4 Modelling software

SimaPro 9.4.0.2 (classroom license) was the software used for the assessment in this study, the method for assessment was IPCC 2021 GWP 101 (version 1.01). Microsoft Excel has been used for calculations and result presentation. For visualization e.g., system boundaries Microsoft PowerPoint has been used.

2.5 Life cycle impact assessment

Current study follows the standards of ISO 14044 (2006) and ISO 14067 (2018) for product carbon footprint. The impact categories correlate with the goal and scope of the study. As the main interest for the study was to assess the carbon emissions and to identify the climate hotspots of the product, the focal impact category for current study has been climate change, used as a single impact category. The IPCC CO_2e factors for Global Warming Potential (GWP $_{100}$), include CO_2, N_2O, and CH_4 emissions, the latter are put in relation to CO_2 (Masson-Delmotte et al., 2021).

3. Life cycle inventory

The LCA data is presented per the FU of the study: 1 kg of Rågkusar *from cradle to retail*. The data presented is based on yearly data.

As the recipe for the Rågkusar is confidential the units for the ingredients are not presented in current study. For the result calculations, the exact values have been used.

3.1 Description of life cycle phases

3.1.1 Cultivation, drying and grinding

The first life cycle phase is cultivation of crops: wheat, and rye. Inputs needed for the cultivation are machines, pesticides, fertilizers, fuel, energy, and water. Most crops are cultivated in the region of Västra Götaland, in Southern Sweden (Fazer, 2022b). After the crop has been harvested, the grains are transported to a distributor that dries the grain. The transportation distance from the field to the distributor is usually approximately 10 km, the transportation is usually done by tractor. The moisture content of the wheat and rye grains after harvesting is circa 15-16%, after drying the moisture content of the grain is circa 13.5%. This process is fueled by a solid fuel boiler, district heating and electricity. In case of any malfunctions, the process can be driven by an oil boiler. The side stream (waste) is ca 1.1 g, out of which two thirds goes back into fueling the process. The remaining third goes to biogas production, assumed to replace petrol production. Thereafter, the grains are transported to the mill, Fazer Kvarn, in Lidköping by a full trailer (38-43 t payload capacity). The transportation distance is 35 km (Fazer's supplier 1, 2022).

After the grains are received at the mill, a sample is taken to ensure quality; the grains are then run through a magnet to clean out any metal parts which may have been included from previous steps. This is followed by a pre-cleanse and storage. After, the grains are run through fine cleaning and then stored until run through a second magnet cleanse and grinded into desired flour. The flour is tested and then stored. This leads to the products: graham flour and rye flour. The finished flour is then transported to Fazer bakery through a pipeline connecting the buildings.

Therefore, no packaging is required for the flours. The process is fully powered by electricity. The amount of waste side streams was assumed to be 0.4 g, these go to animal feed production for pigs (Fazer, 2022c). The inputs and outputs are presented in tables 1 and 2.

Table 1. Data of cultivation, transportation to drier and process for drying.

	Amount	Unit	Source	Dataset[1]
Inputs				
Wheat and rye cultivation, Sweden & Finland*	610-620**	g	Fazer, 2022b	1,2,3
Transport of grain to drier, Sweden	10	km	Fazer's supplier 1, 2022	4
Transport of grain to mill, Sweden	35	km	Fazer's supplier 1, 2022	5
Transport of grain to mill, Finland	110	km	Fazer, 2022d	5
Energy consumption for drying, Sweden	0.026	kWh	Fazer's supplier 1, 2022	6
Transport of side stream	37	km	Google maps, n.d	7
Avoided petrol production	-0.25	g	Balat & Balat, 2009; U.S. Department of Energy, 2021	8
Avoided petrol combustion	-0.006	MJ	RED II, 2018	30
Outputs				
Wheat and rye grains, Sweden & Finland*	610-620**	g	Fazer, 2022b	1,2,3
Side stream at drier, biogas production	~0.4	g	Fazer's supplier 1, 2022	9

**Drying included in dataset for Finland.*

***Depending on slight alterations in recipe.*

[1]*Datasets used in SimaPro, see Appendix 1.*

The ingredient rye fiber is produced in Finland. The transportation distance between the farm and the mill is approximately 110 km (Fazer, 2022d), transported via truck assumed to be 16-32 t payload capacity. At the mill, a quality sample of the grain is taken from the grains in the truck. The rye grains are then unloaded, meanwhile, another automatic sample is taken to further ensure the quality of the grains. During the intake, the grains are run through a pre-cleanse, including a magnet. Then, the grains are stored in silos before being moved to specific mill silos. In the silos, the grain is run through final cleanse and grinded into fiber. Rye fiber consists of rye bran which is grinded into a fine fiber. The fiber is analyzed and packaged in bags for transport. The process in the mill is fully fueled by renewable electricity. The waste side stream is approximately 0.03 g and is directed towards biogas production (Fazer, 2022d), which was assumed to replace petrol. The transportation to Lidköping is performed with truck (28-32 t payload capacity) and ferry, the transportation by truck is approximately 694 km, the transportation with ferry is approximately 206 km (Google Maps, n.d.).

Table 2. Data for the flour and rye fiber production at Fazer.

	Amount	**Unit**	**Source**	**Dataset[1]**
Inputs				
Wheat and rye grains, Sweden & Finland*	610-620**	g	Fazer, 2022b	1,2,3
Energy consumption, grinding Sweden	0.052	kWh	Fazer, 2022b	10
Energy consumption, grinding Finland	0.0046	kWh	Fazer, 2022d	10
Transport of side stream, Sweden	3	km	Google maps, n.d	7
Transport of side stream, Finland	79	km	Google maps, n.d	7
Avoided animal feed production	-5.2	g	Brancoli et al., 2017	11
Avoided petrol production, Finland	-0.87	g	Balat & Balat, 2009; U.S. Department of Energy, 2021	8
Avoided petrol combustion	-0.02	MJ	RED II, 2018	30
Outputs				
Wheat and rye flours and fiber, Sweden & Finland*	605-615**	g	Fazer, 2022b	1,2,3
Side stream, Sweden, feed production	~5.2	g	Fazer, 2022b	11
Side stream, Finland, biogas production	~0.03	g	Fazer, 2022d	9

**Drying included in dataset for Finland.*

***Depending on slight alterations in recipe.*

[1]*Datasets used in SimaPro, see Appendix 1.*

3.1.2 Baking and packaging

Apart from the flours grinded at the mill in Lidköping and the rye fiber from Finland, the ingredients yeast, ferment, salt, and water are required for baking (see table 3). These products are transported to the bakery, apart from water which is tap water and therefore not transported. The yeast is produced in Sollentuna, with raw materials from Europe. The yeast is transported in tanker trucks; therefore, no packaging material is needed (Fazer's supplier 2, 2022). The transport with the tanker trucks has a 40 t payload capacity, and the transportation distance was assumed to be 397 km (Google Maps, n.d). The ferment is a dried sourdough, which comes from Italy, where the production is located. The transportation is to 75%

performed through intermodal transport, a combined transport of train, ferry, and truck. The transport by train was assumed to be 1096 km, the ferry transportation is 232 km, and truck distance is 566 km (40 t payload capacity). 25% of the transports are done entirely by truck (40 t payload capacity), with the total distance of 2014 km (Fazer’s supplier 2, 2022). The ingredient salt is mined and produced in Denmark and packaged in large plastic bags made from polypropylene. The transport is performed with trucks, 28 t payload capacity and the distance is approximately 150 km (Fazer’s supplier 3, 2022). At the bakery, the salt is mixed with water, the salt solution then consists of approximately a third salt and two thirds water. Another ingredient is sourdough which comes from the bakery, the sourdough batch is regularly fed with rye flour and water (Fazer, 2022f).

At Fazer bakery the ingredients are initially stored, next the ingredients are measured and mixed in a kneading machine. Afterwards the dough is fermented, divided into the shape of the bread and baked. After the baking, the bread gets cooled down, gets sliced, and is lastly packaged. Electricity is used in all steps during this process, apart from the cooling process that does not require energy usage. The energy sources used are renewable electricity and fossil oil (78% and 18%). The side stream related to the bakery comes from various phases of the process. These being raw materials, dough, cleaning dust, baked unpackaged bread, baked packaged bread and scrap packaging. The waste reason varies, e.g., broken products, unachieved quality or for hygienic reasons. The total scrapping percentage is approximately 6 (60-65 g), which goes to biogas production and was assumed to replace petrol production.

Table 3. Data for baking and packaging at Fazer bakery.

	Amount	**Unit**	**Source**	**Dataset[1]**
Inputs				
Flour	35-45	%	Fazer, 2022b	1,2,3
Water	30-35	%	Fazer, 2022b	16
Yeasts	1-4	%	Fazer, 2022b	-
Salt	1-4	%	Fazer, 2022b	17
Sourdough (wet)	20-25	%	Fazer, 2022b	1,16
Plastic bag	12	g	Fazer’s supplier 4, 2022	18
Bread clip	6	g	Fazer’s supplier 5, 2022	19,20
Label	3	g	Fazer, 2022f	21
Cardboard	62	g	Fazer’s supplier 6, 2022	22
Plastic film	0.075	g	Fazer, 2022f	23
Energy consumption for Lidköping bakery	0.023	kWh	Fazer, 2022e	10,24

Transport of side stream	2	km	Google maps, n.d.	13
Avoided petrol production	-40-45	g	Balat & Balat, 2009; U.S. Department of Energy, 2021	8
Avoided petrol combustion	~-0.7	MJ	RED II, 2018	30
Outputs				
Finished packaged bread	1022	g	Fazer, 2022b	-
Side stream bakery, biogas production	~60-65	g	Fazer, 2022b	9

[1]Datasets used in SimaPro, see Appendix 1.

The exact ingredient list is company confidential and not presented in current study. However, the precise data is used in all calculations for the results. The percentage for ingredients is in accordance with previous research by Espinoza-Orias et al. (2011).

The bread is then packaged in a plastic bag made of LDPE plastic and is closed off by a bread clip. The product is also labeled with a sticker, with e.g., expiry date (Fazer, 2022f). The LDPE plastic bag is produced in Latvia, the origins of the raw materials are spread out through Europe. The production is fueled by Lettish suppliers for energy and gas. The plastic bags are packed in cardboard boxes, 2000 pcs/box, with 30 boxes per pallet. The pallets are wrapped in plastic film and transported by truck and ferry to Lidköping bakery (Fazer's supplier 4, 2022). The truck was assumed to have 40 t payload capacity and the transportation distance of 571 km, the ferry is assumed to have the transportation distance of 275 km (Google Maps, n.d.). The bread clip is produced in Poland and consists of 62.5% metal wire and 37.5% plastic (polypropylene) and dye. The production is fully fueled by electricity. The bread clips are delivered as rolls of 500 m, with the weight of 4.2 kg per roll. When transported, the rolls are packed in cardboard boxes and placed on pallets (Fazer's supplier 5, 2022). The transportation is done by truck and ferry and the distance was assumed to be approximately 854 km by truck (40 t payload capacity) and 113 km by ferry (Google Maps, n.d.) When the bread is packaged, the bread clip roll gets cut into the size of circa 45 mm (Fazer, 2022f). The label for e.g., date is produced in Denmark, and has the transportation distance of 700 km, with the assumed size of the truck of 40 t payload capacity (Google Maps, n.d.).

Furthermore, cardboard boxes and plastic film are used for packaging the bread. The cardboard is produced in Norrköping and consists of high-performance fluting paper in the outer and inner lining. The core part consists of semi chemical fluting. The cardboard box consists of 41% recycled fiber and weighs 290 g. The production is fueled by electricity and by a pellet boiler. The cardboard boxes are tied up with cable ties, stacked on pallets and wrapped in plastic film. These are then transported via trucks with full trailers (40 t payload capacity) 261 km (Fazer's supplier 6, 2022). The plastic film is produced in Ljungby, the transportation distance is circa

225 km (40 t payload capacity) (Google Maps, n.d.). Lastly, the cardboard boxes are filled with finished bread, stacked, placed on pallets, and wrapped in plastic film. The pallet has been excluded from current study as it is reused time after time and transports several hundred kilograms of bread per transport.

Table 4. Transportation distance of raw materials and their transport to Fazer bakery.*

	Amount	Unit	Source	Dataset[1]
Inputs				
Rye fiber transport	900	km	Fazer, 2022d	13,25
Yeast transport	340	km	Google Maps, n.d.	5
Ferment transport	1894/2014	km	Fazer's supplier 2, 2022	5,25,26
Salt transport	150	km	Google maps, n.d.	7
Plastic bag transport	846	km	Google maps, n.d.	5,25
Label transport	700	km	Google maps, n.d.	5
Cardboard transport	261	km	Fazer's supplier 6, 2022	5
Plastic film transport	225	km	Google maps, n.d.	5

[1]Datasets used in SimaPro, see Appendix 1.

**Flours produced at Fazer mill Lidköping are excluded as transport of flours is carried out through a pipeline connecting the buildings.*

3.1.3 Transport, distribution, and retail

About 96% of the finished bread is transported to a distributor site, via truck (28 t payload capacity), the distributor then performs the last transport to retail. The weighted transportation distance to a distributor site is 280 km. 37% of the transportation is fueled with HVO-diesel, 63% via fossil diesel of current mix. Then, without further storage, the bread is transported to retail (Fazer 2022e), the weighted transportation distance to an average retail site is 222 km. These transports are performed with trucks assumed to have a payload capacity of 16-32 t. 36% of these transports are fueled by HVO-diesel, 15% are fueled by RME-diesel, and 49% fossil diesel (Fazer 2022e). To account for any additional stops and for the return trips of these trucks, the route distance was assumed to be 502 km (the weighted transportation distance). However, these transports are assumed to carry the weight of 20% of the bread. Approximately 4% of the finished breed freezes and goes to a separate distributor. The transportation to the distribution site is 115 km, transported via trucks with a payload capacity of between 25-40 t. These transports are done with freeze trucks (reefers), 30% of the transports are performed with HVO-diesel fuel. At the distribution site, the bread is stored frozen. The time at the distribution site varies, often it is stored only until the next day. Although the bread can also be stored for about a month at the site (Fazer's supplier 7, 2022).

The assumed storage time for the bread is therefore 14 days. The second and final transport for frozen bread is approximately 378 km, transported with freeze trucks with a payload capacity between 25 – 40 t. 38% of these transports are fueled by HVO-diesel fuel (Fazer, 2022g). The return transportation for the trucks was assumed to be 493 km, although with the weight of 20% of the original weight (see table 5).

The cardboard box and plastic film needed for transportation are handled by the distributor at the retail site. The cardboard box was assumed to be recycled and the plastic film was believed to be dispatched to combustible waste.

At the retail site, the assumed storage space for the bread was 0.015 m². The bread is usually sold after 2-6 days (Fazer, 2023b), the average retail storage time was therefore assumed to be 4 days. The product is thereafter expected to be bought and consumed. Approximately 10% of bread delivered to retail is not sold but is instead collected as a waste side stream of which 99.5% is sent to bioethanol production in Norrköping (Fazer 2022b), which was assumed to replace petrol production. See table 5 for the inputs and outputs during this phase.

Table 5. Data for distribution, retail, and waste management.

	Amount	**Unit**	**Source**	**Dataset[1]**
Inputs				
Transport to distributer	280	km	Fazer, 2022g	7,12
Transport to retail	222	km	Fazer, 2022g	7,12
Return transport	502	km	Google Maps, n.d.	7,12
Reefer transport to distributer	115	km	Fazer's supplier 7, 2022	27
Reefer transport to retail	378	km	Fazer's supplier 7, 2022	27
Return reefer transport	378	km	Google Maps, n.d.	27
Storage at retail	0.011	kWh	DEFRA, 2008; Swedish Energy Agency, 2010	6
Frozen storage	0.006	kWh	Fazer's supplier 7, 2022	6
Transport of unsold bread	502	km	Google maps, n.d.	7,27
Avoided petrol production	-68	g	Balat & Balat, 2009; U.S. Department of Energy, 2021	8
Avoided petrol combustion	-1.7	MJ	RED II, 2018	30
Avoided cardboard production	-31	g	Fazer's supplier 6, 2022	28
Avoided energy production	-0.0007	kWh	Müller et al., 2004	29
Outputs				
Cardboard	62	g	Fazer's supplier 6, 2022	28

Plastic film	0.08	g	Fazer, 2022f	29
Side stream, unsold bread, bioethanol production	~102	g	Fazer, 2022b	9

[1]*Datasets used in SimaPro, see Appendix 1.*

4. Results

This section presents the results of the life cycle assessment (LCA). The results are presented per the FU for the study: 1 kg Rågkusar. It should be noted that the results are approximate representations that signify the potential climate impacts, not exact values, or exact impacts.

The GHG emissions are presented depending on type of impact: fossil fuels (CO_2 emissions), biogenic emissions (N_20); defined as carbon contained in biomass that accumulate during photosynthetic growth processes, and land transformation (CH_4); transformation and occupation of land (Wiloso et al., 2016; Fthenakis & Kim, 2009).

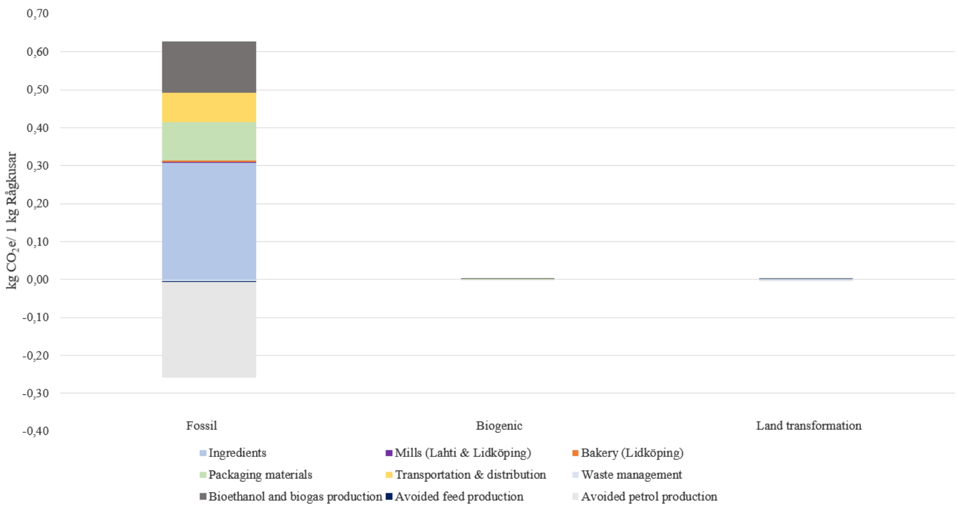
4.1 GHG emissions and life cycle interpretation

The total result: fossil, biogenetic and land transformation GHG emissions generated in the assessed system are presented in table 6. The results also present the avoided emissions of substitution processes. The total GHG emissions stand for 0.37 kg CO_2e (substituted processes included, e.g., avoided petrol production), which is the carbon footprint of 1 kg Rågkusar. Out of these, the ingredients stand for 0.3 kg CO_2e, followed by the packaging materials 0.1 kg CO_2e, and transportation and distribution 0.1 kg CO_2e.

Table 6. Generated GHG emissions for 1 kg Rågkusar.

	Amount	**Unit**
Fossil GHG emissions	0.37	kg CO_2e
Biogenic GHG emissions	0.00	kg CO_2e
Land transformation GHG emissions	0.00	kg CO_2e
Total	0.37	kg CO_2e

Figure 3 presents how the GHG emissions are spread out through the life cycles. For fossil emissions, the ingredients contribute the most to the total amount of fossil GHG emissions, 83%. Bioenergy production and avoided production have the second largest contribution 37%, this is followed by packaging materials 28% (the bread clip stands for 3%) and transportation and distribution (21%). The remaining phases have a smaller impact (< 10%) to the total fossil GHG emissions, as seen in figure 3. Packaging materials have the largest impact on the biogenic GHG emissions, 76%, followed by bioenergy production, 24%. Bioenergy production has the largest impact on the land transformation GHG (see figure 3).



GHG emissons	Ingredients	Mills (Lahti & Lidköping)	Bakery (Lidköping)	Packaging materials	Transportation & distribution	Waste management	Bioethanol and biogas production	Avoided petrol production	Avoided feed production	Σ
Fossil	83%	0%	1%	28%	21%	-1%	36%	-68%	-1%	100%
Biogenic	4%	3%	1%	76%	2%	-3%	24%	-2%	-6%	100%
Land transformatior	38%	0%	0%	35%	7%	-82%	141%	-1%	-37%	100%
Total	83%	0%	1%	28%	21%	-2%	37%	-67%	-1%	100%

Figure 3. The contributions of GHG emissions throughout the life cycles.

4.2 Sensitivity analysis

Several sensitivity analyses using the scenario technique were carried out in this study to distinguish any uncertainties in the results. In this section different datasets have been used in the sensitivity analysis to compare the difference between the base case and the scenario.

4.2.1 Cultivation

Organically grown grains have previously shown to result in a reduced environmental impact, except for land usage (Braschkat et al., 2004). As Rågkusar is a non-organic product without any organic cultivation a sensitivity analysis was performed to analyse how the result would differ if Fazer changed to organic cultivation. The result showed that organic cultivation would lower the carbon footprint (see figure 8). A shift to organic cultivation could lower the overall GHG emissions by approximately 22%.

Table 7. The results of sensitivity analysis in which a different dataset for organic cultivation was used.

Scenario	Amount	Unit	Dataset[1]
Base case (non-organic cultivation)	0.37	kg CO_2e	1,2,3
Sensitivity analysis (organic cultivation)	0.29	kg CO_2e	4,5,6

[1]*Datasets used in SimaPro, see Appendix 2.*

4.2.2 Energy sources

One of the common environmental hotspots for bread production is the energy needed for production, the choice of energy source can be influential for the environmental impact (Grönroos et al., 2006). Approximately 18% of the energy needed for production of Rågkusar comes from fossil oil. Therefore, a sensitivity analysis was performed to analyse how different energy sources could change the carbon footprint. As seen in figure 9, if the production were fully fueled by electricity, the CO_2e would be slightly lower (2%). On the other hand, if the production was fully fueled by gas, the CO_2e would be slightly higher (5%).

Table 8. The results of a sensitivity analysis in which different datasets for energy sources were used.

Scenario	Amount	Unit	Dataset[1]
Base case (combined energy sources)	0.37	kg CO_2e	7,8
Sensitivity analysis (electricity)	0.36	kg CO_2e	7
Sensitivity analysis (oil)	0.39	kg CO_2e	8

[1]*Datasets used in SimaPro, see Appendix 2.*

4.2.3 Side streams in production

The direction of the side streams can have a substantial impact on the environmental impact of bread waste (Brancoli et al., 2017). For Rågkusar, the side stream in the production line in Lathi mill and Lidköping bakery are directed towards bioenergy. Sensitivity analyses were conducted to see the difference between the base case of bioenergy compared to different types of animal feed production. Shifting direction of the side stream in Lidköping bakery to animal feed production would reduce the overall carbon footprint by 0-2% depending on the type of animal feed. The change in Lathi mill would not change the results, due to the small side stream.

Table 9. The results of a sensitivity analysis in which different datasets were used for side streams at the bakery.

Scenario	Amount	Unit	Dataset[1]
Base case (bioenergy)	0.37	kg CO_2e	9,10,11
Sensitivity analysis, Lahti mill (sow compound animal feed)	0.37	kg CO_2e	11,12
Sensitivity analysis, Lahti mill (rye grain animal feed)	0.37	kg CO_2e	11,13
Sensitivity analysis, bakery (sow compound animal feed)	0.36	kg CO_2e	11,12
Sensitivity analysis, bakery (rye grain animal feed)	0.37	kg CO_2e	11,13

[1]*Datasets used in SimaPro, see Appendix 2.*

4.2.4 Fuels for distribution transport

The environmental impact from transportation fuel varies depending on type, e.g., biodiesel is favoured over fossil diesel. However, transports performed by electric trucks have shown to have a much smaller environmental impact compared to other fuels (Liimatainen et al., 2019). Currently, the distribution of Rågkusar is performed with different types of fuels. Since the type of fuel varies, a sensitivity analysis was made to compare the several types of fuels. The datasets used in the combined fuels base case were used in the sensitivity analysis, furthermore a dataset for an electric truck was added. Lastly, a calculation for a combined transportation for electric and biodiesel (RME) was added. In this scenario, 59% of the transports would be performed with electric trucks and 41% would be performed with biodiesel trucks. This percentage estimate is based on the current power range for electric trucks, 250 km (Scania, n.d; OKQ8, n.d.). Table 10 indicates that the carbon footprint for Rågkusar would remain the same if fossil diesel were the only fuel used for the distribution transport. It would be slightly reduced if all the distribution transports were fueled by biodiesel (2%). However, shifting to electric trucks indicates the largest reduction and would reduce the overall CO_2e by approximately 16%. If electric and biodiesel trucks were used, the reduction from the current total CO_2e would be approximately 15%.

Table 10. The results of a sensitivity analysis in which different datasets for transportation fuels were used for the transport of nonfrozen bread.

Scenario	Amount	Unit	Dataset[1]
Base case (combined fuels)	0.37	kg CO_2e	11,14
Sensitivity analysis (fossil diesel)	0.37	kg CO_2e	11

Sensitivity analysis (biodiesel)	0.36	kg CO_2e	14
Sensitivity analysis (electric)	0.31	kg CO_2e	-
Sensitivity analysis (electric and biodiesel)	0.32	kg CO_2e	14

[1]*Datasets used in SimaPro, see Appendix 2.*

4.2.5 Side stream at retail

Bread waste has shown to have one of the highest environmental impacts amongst food waste in retail, furthermore the side stream direction has the potential to influence the environmental impact of a product or system, shifting to animal feed could have the potential to reduce the impact considerably (Brancoli et al., 2017). For Rågkusar, the retail side stream is 10%. Therefore, a sensitivity analysis was performed to analyse how the results would differ if the direction of the side stream was changed to animal feed instead of bioethanol. In this analysis the bread packaging was assumed to be directed towards combustible waste. Two different datasets for animal feed were used (see table 11). In addition to this, a sensitivity analysis was conducted for a reduced side stream, 5% instead of 10%. This was performed by reducing the total production with 5%. Table 11 demonstrates that the carbon footprint for Rågkusar would change if side stream at retail was animal feed instead of bioethanol (base case), this could possibly decrease the carbon footprint by 6% or increase if by 3%. Furthermore, if the side stream were reduced to 5% the CO_2e would decrease and lower the total CO_2e for Rågkusar by approximately 15%.

Table 11. The results of a sensitivity analysis in which different datasets of the side stream at retail were used.

Scenario	**Amount**	**Unit**	**Dataset[1]**
Base case (bioethanol)	0.37	kg CO_2e	9,10,11,14
Sensitivity analysis (sow compound animal feed)	0.35	kg CO_2e	11,12,14
Sensitivity analysis (rye grain animal feed)	0.38	kg CO_2e	11,13,14
Sensitivity analysis (reduced side stream)	0.31	kg CO_2e	-

[1]*Datasets used in SimaPro, see Appendix 2.*

5. Discussion

The aim for current study has been to find the carbon footprint of Rågkusar, identify the life cycles that contributes the most to this, and to find improvement possibilities in the life cycles.

5.1 Climate impact

5.1.1 Carbon footprint

This study had the scope *from cradle to retail*, which resulted in a total carbon footprint of 0.37 kg CO_2e. Ingredients had by far the largest impact on the carbon footprint (0.3 kg CO_2e), followed by packaging materials (0.1 kg CO_2e) (see figure 3). The most important outcome of this study was identifying the carbon footprint of Rågkusar and its climate hotspots throughout the life cycles to find improvement possibilities.

The scopes for previous research have varied, e.g., cradle to grave (with consumption included), cradle to gate and cradle to gate with retail transportation included. For instance, 1 kg of Danish rye bread was shown to represent 0.73 kg CO_2e, in the scope of cradle to grave, with consumption (ambient storage and toasting) and end of life of consumer packaging included (Jensen & Arlbjørn, 2014). Another study by Nielsen et al. (2003), in a cradle to retail scope, showed that 1 kg of rye bread represents 0.79 kg CO_2e, and that 1 kg wheat bread had a slightly higher carbon footprint of 0.84 kg CO_2e. Espinoza-Orias et al. (2011) have compared several types of breads to see a difference in the carbon footprint amongst the breads. Their result showed that 1 kg of bread had CO_2e values ranging between 0.98 kg and 1.2 kg, depending on type of bread and size of the slices of the bread. The bread with the lowest carbon footprint was the wholemeal thickly sliced bread packed in plastic bags. The bread with the highest carbon footprint was the white bread in medium-slices packaged in a paper bag. Their study included the consumption of the bread, assuming that the bread would be refrigerated and toasted. Furthermore, they claim that by avoiding the toasting and the refrigerated storage the carbon footprint would on average be reduced by 25% (Espinoza-Orias et al., 2011). Goucher et al. (2017) has studied the carbon footprint of wheat bread in a cradle to gate scope, they found that 0.8 kg of wheat bread stands for 0.59 kg CO_2e.

The carbon footprint found in current study is lower than has been presented in previous studies. There could be many reasons for this, e.g., due to the different scopes, or due to the fact this is a later study, meaning that there might be a possibility that the product system for bread has been improved (e.g., improved energy sources). Current study has included the waste and the avoided impacts linked to the waste side streams, e.g., avoided petrol production, which some previous studies have excluded. The waste and the avoided productions have a clear impact on the total carbon footprint, as seen in figure 3. Also, there might also be parts in the life cycle that resulted in the lowered carbon footprint, which will be further addressed in the following section.

5.1.2 Climate hotspots

Previous research has found that raw material cultivation has the largest environmental impact, thus being a clear environmental hotspot for bread (Notarnicola et al., 2017; Espinoza-Orias et al., 2011; Jensen & Arlbjørn, 2014). The result from current study follows prior research in this regard. For Rågkusar, the primary ingredients are flour and water (see table 3), meaning that the impacts likely have strong associations to the cultivation phase. Earlier studies have shown that the type of grain can influence the carbon footprint, with whole grain- and rye flour having a lower impact than wheat (Espinoza-Orias et al., 2011; Nielsen et al.; 2003). Rågkusar is a rye bread that consists mainly of the flours: rye- and graham flour. Graham flour comes from wheat; however, rye flour is the main ingredient for Rågkusar. Based on previous studies, it is possible to believe that Rågkusar has a lower climate impact thanks to its rye flour, than it would with a higher wheat content. As of today, Rågkusar is a non-organic product. Although, if cultivation instead were performed organically the carbon impact would possibly be lower, as seen in the sensitivity analysis in table 8. The CO_2e of non-organic cultivation is likely to be higher due to e.g., use of machinery and production of fertilizers and other pesticides (Notarnicola, et al., 2017). Some prior research has shown comparable results; organically grown grains have a better impact on the environmental impact compared to non-organic cultivation, apart from land use (Braschkat et al., 2004). On the other hand, other studies have shown that organic cultivation can have a higher global warming potential than non-organic cultivation (Meier et al., 2015).

The packaging materials was found to have a large impact on the climate footprint, 0.1 kg CO_2e out of the total 0.37 kg CO_2e. Previous studies have shown that packaging materials can be a substantial part of the environmental impact of a product (Cellura et al., 2012). Williams and Wikström (2011) have analysed the environmental impact of bread packaging, they found that the packaging for 1 kg bread represents 0.28 kg CO_2e. This value also includes the waste handling of the plastic bag. This is a higher value than what is found in current study (0.1 kg CO_2e), however, present study only included the climate impact and did not include the waste handling of consumer packaging. In prior LCAs performed to analyse bread, the packaging materials have either only been included to some extent or are shown to have a small impact. E.g., Notarnicola et al. (2017) included packaging materials whenever possible, but these showed a low impact on the environment. Espinoza-Orias et al. (2011) had packaging materials included in the scope, nevertheless, these were similarly found to have a rather small impact. Although, they found paper bags to be preferred over plastic packaging. On the other hand, Cellura et al. (2012) observed that packaging materials for food products can have a high contribution to the environmental impact and concluded that these are a great possibility for future improvements. For Rågkusar, the impact of the packaging material is the second to largest hotspot and can therefore not be dismissed as small, for Fazer this could therefore be an opportunity to reduce the climate impact of the bread.

The energy consumption required for bread baking has previously been shown to have the second largest impact (Braschkat et al., 2004; Jensen & Arlbjørn, 2014). In current study, the bread production was shown to have a smaller impact: 0.005 kg CO_2e / 1 kg Rågkusar. The production is powered by renewable electricity and fossil oil. The electricity used for the production is hydropower, it has a GWP of 0.7 kg CO_2e / 1 kWh (Vattenfall, 2021), the dataset used to model the renewable energy has a GWP of 1.1 kg CO_2e / 1 kWh. Hence, if the hydropower value had been used in calculation the impact for 1 kg Rågkusar could possibly have been slightly lower than what is presented in current study. The use of renewable energy could be a potential reason for why the bread production resulted in a lower impact than could be expected. Another possibility has to do with the shape of the bread, Notarnicola et al. (2017) observed that the bread shape influenced the energy needed for baking, e.g., small bread requiring less energy than larger bread due to the exposed surface. The shape of Rågkusar is rather small and flat (see figure 1) and the bread is baked separately, the expected baking time would likely be lower than for a larger bread. Even though the processing result for current study is lower than what could be estimated, there are several likely causes for this result.

In present study, the transportation of the final product and distribution to retail were combined in the calculations. In the results, transportation and distribution were shown to be the third largest climate hotspot, 0.1 kg CO_2e. Andersson and Ohlsson (1999) found transportation to be the second largest contributor to the environmental impact, although they also included consumer transport in their calculations. Other studies have also included consumer transports, often by assumed means of transport and distance (Braschkat et al., 2004; Kulak et al., 2015). Kulak et al. (2015) found that the results were sensitive to the choice of dataset used to model consumer transportation, hence, the results could differ greatly depending on type and distance of transport. Some prior research had transportation to retail and retail storage included in their scope (Notarnicola et al., 2017; Kulak et al., 2015), yet these found the effects to be smaller compared to findings in current study. Espinoza-Orias et al. (2011) assumed the transportation distance from bakery to retail to be 50 km and assumed the storage time at retail to be one day. These estimates are much lower than the ones used in present study, Rågkusar are distributed throughout Sweden, thus including long distances for the transports to retail (502 km). The expected time for bread at retail was in current study assumed to be four days. This could be one possibility of why the results in present study are somewhat higher than what some of the previous ones have found. Weber et al. (2023) assessed the transport system for bread in Sweden and found long-distance to be the greatest contributor to the climate impact. Their findings also indicated that the current transportation system could be improved and thus, increase the environmental sustainability within the supply chain. Cellura et al. (2012) had a similar conclusion: transportation in food product systems can be a major contributor to the environmental impact of a product, hence giving an opportunity for future development. For Fazer, this could be a possibility to lower their emissions by further exploring their distribution patterns and alternatives.

Bread waste has in previous studies shown to be a large share of the total food waste in Sweden, furthermore, bread waste at retail has proved to have one of the larger environmental impacts of food waste (Brancoli et al., 2020; Brancoli et al., 2017). For Rågkusar, the bread waste at retail is 10%. Brancoli et al. (2017) found that some directions of waste are preferred over others. Furthermore, an improved waste scenario at retail would be to shift the direction towards donation or animal feed with plastic recycling (Brancoli et al., 2017), likely due to the utilization of the resources. Current study has found the side stream in the base-case to be efficient, however, shifting it towards animal feed could possibly lower the CO_2e if directed correctly (see table 12). However, actual effect would depend on what the bread waste possibly could replace.

5.2 Potential improvements for Rågkusar

The LCA results were presented during discussion workshops with essential staff members from the production line at Fazer. Based on findings of key elements for CO_2e in the production, discussions were held to find improvements to these. These lead up to the following areas: the cultivation and mill process, the baking and packaging process, transport, distribution, and retail.

5.2.1 Cultivation and grinding

Some previous studies have found that moving to organic cultivation has the potential to reduce the environmental impact in bread production (Braschkat et al., 2004). This is also found in the sensibility analysis regarding the climate impact of Rågkusar (see table 8). If Rågkusar was produced by organic cultivation the overall CO_2e impact for 1 kg of Rågkusar would be lowered, resulting in a reduction of 22%. Therefore, a potential improvement for Rågkusar could be to increase the use of organic grains in the bread.

Fazer had previously considered moving to organic grains and mentioned that some previous studies have shown that good farming practices can have the same or better impact due to higher yield. Fazer already has a set of goals for their grain use, called “grain vision”, including several steps for ensuring sustainably produced grains. Fazer mentioned some potential roadblocks for a shift towards organic cultivation, e.g., organic farming requires bigger land usage, which would potentially lead to a food security problem if all cultivation was organic. Prior research has shown that conventional cultivation systems require 65% of the land area required for organic cultivation (Braschkat et al., 2004). Furthermore, another potential roadblock for organic cultivation is the price for organic grains, which is 50% more or double (depending on harvest) compared to current price. The price of organic grains would also impact the price of the final product. Fazer described how they expanded their line of organic breads in the past, but that these products did not sell as well as their non-organic breads, potentially due to the higher price. Fazer market analysis has shown that the demand for organic products has decreased (Fazer, 2022h).

Shifting towards organic cultivation could have a potential to reduce the impact for Rågkusar. Although, present study has only assessed the climate impact of the bread. Yet there might be aspects, both positive and negative in an environmental perspective, associated with organic cultivation not accounted for the present study. However, some studies have shown that organic cultivation can have a higher global warming potential compared to non-organic cultivation (Meier et al., 2015). The recommendation for Fazer is therefore to further look into their cultivation and good practices, a suggested focus is to find alternatives for fertilizers and pesticides as they contribute to a large part, 40%, of the environmental impact of agriculture (Goucher et al., 2017).

As animal feed has previously shown to be a preferred side stream utilisation, compared to e.g., electricity or heat production (Brancoli et al., 2017), animal feed production was considered for rye fiber production as the side streams currently are directed towards bioenergy. When modelled, a shift towards animal feed would lower the CO_2e by < 1%. Fazer described that changing this side stream to animal feed would not be possible as it only consists of impurities, broken kernels, and some dust from grinding. The side stream can also include ergot, a type of fungus that should not be consumed by nor human or animal (Fazer, 2022h). This side stream might not be possible to improve, however, to shift direction of other side streams towards animal feed would possibly lower Fazer's GWP, therefore they are recommended to further consider this option for their production.

5.2.2 Baking and packaging

Energy for bread production has previously shown to impact the products carbon footprint, (Grönroos et al., 2006), therefore was a topic for discussion with Fazer as they partly use fossil oil in their bakery. As the result in the sensitivity analysis on this topic suggests, shifting fully to electricity as energy source would slightly lower the climate impact (see table 8). Fazer are aware of the drawbacks due to their oil machinery and would prefer to exchange it (Fazer, 2022i).

The waste side stream in the bakery is approximately 6% and is fully directed towards bioenergy production. Animal feed is assumed to be a superior use of food waste, with shifting to feed having the ability to decrease the carbon footprint (Brancoli et al., 2017). Shifting the direction of the side streams to animal feed could possibly lower the overall CO_2e impact for Rågkusar (see table 9). Therefore, this suggestion was further discussed with Fazer. Fazer explained the several roadblocks; the side stream can not be readily used as animal feed because it is a mixture: dough, baked bread with and without packaging, and cleaning dust, etc. Furthermore, as the amount of waste is rather large, it is possible that no single farmer would be able to use all of it. Thus, risking that some of the waste would not be utilised. On the other hand, the bioenergy producer can purposely use all the waste, and is still, as seen in table 9, a good utilisation of the side stream. Although, Fazer mentions that an improvement could be to sort out the dough and send that to feed production. If Fazer were to redirect their side stream towards animal feed, they would have to get a permit by the Swedish board of agriculture. Chances are that shifting to animal feed would be a financial setback, as the farmers pay a very small (or no) amount for receiving the waste, in contrast to the bioenergy producer that buys the waste (Fazer, 2022i). For Fazer, shifting their direction of side stream could possibly reduce their climate impact slightly. It could be a preferred side stream as it utilises existing food, therefore, Fazer are recommended to further look into their options for direction their side stream towards animal feed as it possibly could reduce their GWP.

Packing materials were found to be the second largest climate hotspot for Rågkusar (0.1 kg CO_2e). Therefore, a proposed potential improvement was to replace a part of the packaging, the bread clip, which would lower the overall CO_2e for Rågkusar by 3%. Fazer was aware of the problem and are currently trying to find a solution for replacing the metal part of the clip (Fazer, 2022i). The metal part of the clip contributes the most to its CO_2e, the recommendation for Fazer is to assess the climate impact of exchanging it with a plastic clip or sealing the existing bag.

5.2.3 Transport, distribution, and retail

Rågkusar is distributed throughout all of Sweden, hence, the transportation distances are long and have a large impact on the bread's climate impact. Currently the transportations are fuelled with fossil diesel and biodiesel (RME and HVO). Biodiesel is favoured over diesel, although electric trucks can improve the climate performance (Liimatainen et al., 2019). This is also in line with findings in current study (see table 10). However due to the long distances the current electrical trucks would not be able to perform the journey in a single trip. An alternative would be to combine electric trucks with biodiesel trucks for the longer distances. Fazer sees this as a viable change and are already looking into cooperations with transportation partners.

The retail side stream for Rågkusar is 10% and is directed towards bioethanol production. Animal feed is seen as a preferred side stream (Brancoli et al., 2017), and could, if directed properly reduce the carbon footprint for Rågkusar (see table 11). Furthermore, reducing the side stream to 5% instead of 10% has a clear lowering potential for Rågkusar. Therefore, these were suggested as improvements for Fazer. Fazer agreed that shifting to animal feed rather than bioethanol would be an improvement, however there are a few roadblocks for this. Yet again, the bakery would have to be licensed for animal feed by the Swedish board of agriculture for the waste to be approved for animal feed. Additionally, the plastic bag must be handled, which the current system is not set up for. Even if shifting to animal feed would be an improvement, Fazer argued that human consumption would be the preferred scenario for the bread waste. Fazer are looking into solutions for this, such as price reductions for bread about to expire (sold frozen), or recommending retailers to use apps for this (such as "*Karma*" or "*Too good to go*"). Some retailers have already implemented this, and Fazer could possibly influence other retailers to apply this. Concerning the size of the side stream, Fazer described that they are currently working on this issue and are aiming towards a better prognosis for matching the demand with produced bread. Fazer is discussing with the distributor company about how this could change, e.g., implementing smaller shelves at retail, meaning lower bread production and therefore less bread waste. Fazer has some internal discussions on how to improve their retail side stream (Fazer, 2022j), however even with the use of apps or donation systems they will likely have some waste. The recommendation for Fazer is to further look into how they best can reduce their side streams, and to continue exploring their waste options.

5.2.4 Implementations of potential improvements

Several potential implementations have been suggested to Fazer, some of which possess certain roadblocks to achieve. Other improvements, such as replacing or removing the bread clip and changing fuels for transportation, are already being considered. What has come clear whilst mapping out the life cycle for Rågkusar is that there are improvements which potentially could reduce the carbon footprint of the bread. Which of these improvements will be accomplished or not, are in the hands of Fazer. However, present study has only focused on the climate impact and the related GWP, although there are other impacts that Fazer might need to consider in their decision-making.

In the discussions, regarding whether to implement something or not, the dialogue often led back to financial complications. Several of the potential roadblocks were connected to its costs, which is commonly the case for sustainability on a corporate level, the economic aspect plays the centre role (Zimek & Baumgartner, 2017). This could be explained by the fact that corporations are driven by their financial means, which also is true for Fazer. Although, an aspect to consider is that implementing changes in their production that require expenses will likely influence the price of their products. Hence, affecting the market price and the consumer.

5.3 Limitations and uncertainties

To perform an LCA can be a challenging task and requires extensive understanding of the system to be analysed (Notarnicola et al., 2017). This study has been somewhat time limited, and several assumptions have had to be made for the calculations, which is seen as a limitation for this study. Also, return transportations for the raw materials were not included in the current study and were instead assigned to the logistics system outside the scope of this study. A similar assumption was made by Bartek et al. (2021), however, including the return trips for the raw materials could have been an improvement. For parts of the LCA, secondary data had to be used, which can affect the reliability of the study as it provides data with average values rather than exact values. Several sensitivity analyses have been performed to account for any uncertainties, and to compare datasets. Although, a complete assessment of all possible uncertainties would have been too time-consuming and complex. Nevertheless, with more time to analyse the system, it is possible that fewer assumptions would have had to be made.

Another risk of performing LCA's with clear focus on GWP is that other environmental impacts might be overlooked and compromised. For current study this is specifically relevant for the cultivation since organic cultivation is seen as a potential improvement for Rågkusar. Shifting to organic cultivation from non-organic cultivation has shown a lower CO_2e, however other environmental impacts have not been considered in this study. Therefore, future research should consider including additional environmental impacts rather than just focusing on GWP, e.g., resource depletion, ecotoxicity, freshwater toxicity, and ozone depletion.

The use phase for the bread was not considered in this study; therefore, this study is not a full cradle to grave study. However, previous research by Espinoza-Orias et al. (2011) has indicated that the use phase can be a climate hotspot, depending on how the consumer uses the bread, e.g., if bread is frozen or toasted, the energy usage will be higher than if only stored ambiently. Moreover, research by Ungerth (2021) focused on bread waste has shown that the largest amount of bread waste is the household waste. Therefore, there is a risk that the amount of bread waste is higher than presented in current study.

5.4 Future outlook

Present study has mapped out the product system of Rågkusar and assessed the climate impact in the scope *from cradle to retail*. The understanding of the product system showed depth thanks to the insight from Fazer and their suppliers. However, the consumer phase was excluded from the scope in current study. Although, previous research has found the consumer phase to be a possible climate hotspot. Meaning that the type of storage, toasting or waste of the bread could have a considerable impact on the overall CO_2e. For future studies, a potential angle could be to include the use-phase of the bread, which could give a more realistic view of the entire life cycle of the bread. Furthermore, current study has focused primarily on the CO_2e effects throughout the product system. Yet, there are many more environmental impacts that could be considered in an LCA. This is something that future research could further analyse for a better understanding of the full environmental impacts. In this study potential hotspots were found and analysed; also, potential improvements were observed. Another interesting approach could be to analyse how environmental hotspots could be identified depending on their potential for changing the environmental impact. This could be useful when analysing improvements in product systems.

6. Conclusion

Present study has analysed the life cycle, *from cradle to retail*, of 1 kg of the Fazer bread Rågkusar to find its carbon footprint: 0.37 kg CO_2e. The climate hotspots were mainly the ingredients, followed by packaging materials and transportation and distribution of the final product. To some extent, these were in accordance with previous research. However, present study found baking to have a smaller contribution to the GWP than prior studies. Additionally, Fazer was provided with some improvements for how they could reduce the climate impact of Rågkusar, based on sensitivity analyses using the scenario technique. E.g., using more organic grains, reduce their side streams and change the means of transport. The suggested improvements were in line with what previous research.

Thanks to the cooperation with Fazer this study has revealed meaningful depth in the assessed product system. Current study has provided insights of bread production in Sweden, uncovered its climate hotspots, and found potential improvement for reducing its CO_2e. Suggestions for future studies are to include the use phase for a more accurate interpretation of a bread's full life, as well as to assess other impacts related to bread production. All impacts linked to the full life cycle of bread are still to be mapped out, however present study has uncovered parts of it.

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Popular science summary

The world today is facing an increasing food demand because of population growth and economic development. This, together with the continuing climate changes clarifies the importance for sustainable food systems. Meaning systems that meet the present and future needs, with consideration of economic development, social development as well as environmental protection. The current food systems have strong links to greenhouse gas (GHG) emissions, and therefore contributes to climate change. GHG exist in the atmosphere, these are emitted both by natural processes and human activities. Although, the human-driven emissions interfere with the natural process and trap the heat in the atmosphere, creating climate change and global warming. A few common GHG emissions are carbon dioxide, methane, and nitrous oxide.

Evaluation our current food systems can help us improve sustainability; this can be a challenging task as food systems commonly are complex. Life cycle assessment (LCA) can be a useful tool for this and is increasingly used for evaluating the environmental impact of a product, process, or an activity. LCAs make it possible to evaluate the impact from the first to the last phase, or any of the phases in between.

Two drivers towards environmental pressure have been agriculture and food consumption. A typical agricultural good is bread, which is commonly consumed around the world. Bread can include various types of ingredients, sometimes imported from far away. In current study, the rye bread Rågkusar is assessed by conducting an LCA. The bread is produced by Fazer, the commissioner of this study, Fazer represents about 20% of the Swedish market for pre-packaged bread. The aim of the study was to identify the carbon footprint of the bread, its climate hotspots and to find improvement possibilities throughout the life cycles. By mapping out the product system and assessing Rågkusar in the scope of *from cradle to retail*, the carbon footprint was 0.37 kg CO_2e. The main climate hotspot was the ingredients of the bread, followed by the packaging materials. By conduction sensitivity analyses with the scenario technique some potential improvements were found. These improvements would lower the climate impact of Rågkusar, some of these were to use more organic grains, reduce their side streams and shift to electric and biofuel transportations for the final product.

The results found in this study were to some extent in accordance with previous research, e.g., the carbon footprint found in current study is rather low compared to what prior studies has found, several reasons for this are discussed in the study. The climate hotspots are somewhat in line with previous research, which is likewise further discussed in the study. Current study has some limitations, e.g., neither all life cycle phases, nor all environmental impacts are included in the study. However, the study has provided insights of bread production in Sweden thanks to the cooperation with Fazer. All impacts linked to the full life cycle of bread are still to be assessed, however present study has revealed part of it.

Appendix 1

Appendix 1 showing a list of the datasets used in SimaPro 9.4.0.2. Table 12 indicates data generator, name of dataset, geographic location and which process the datasets is used to model. Datasets are set to the Allocation, cut-off by classification.

Table 12. Datasets used.

Number	Data generator	Dataset name	Location	Used to model
1	Blonk Agri-footprint BV	Wheat straw, at farm {SE} Economic, S	SWE	Rye cultivation
2	Blonk Agri-footprint BV	Rye grain, at farm {SE} Economic, S	SWE	Wheat cultivation
3	Blonk Agri-footprint BV	Rye grain, dried, at storage {FI} Economic, S	FIN	Rye cultivation
4	Blaser S., Ecoinvent	Transport, tractor and trailer, agricultural RoW	ROW	Transportation
5	Valebona F., Ecoinvent	Transport, freight, lorry >32 metric ton, EURO5 BR	RER	Transportation
6	Karin Treyer, Ecoinvent	Market for electricity, medium voltage SE	SWE	Electricity
7	Valebona F., Ecoinvent	Transport, freight, lorry 16-32 metric ton, EURO3 BR	RER	Transportation
8	Ecoinvent 3	Petrol production, low-sulfur Europe without Switzerland	RER	Petrol production
9	Gnansounou, E., Ecoinvent	Ethanol production from biomass Europe without Switzerland	RER	Bioethanol production
10	Treyer, K., Ecoinvent	Market for electricity, medium voltage, renewable energy products CH	CH	Renewable electricity
11	Blonk Agri-footprint BV	Sow pig compound feed, at processing {NL} Economic, S	NL	Feed production
12	Valsasina, L., Ecoinvent	Market for transport, freight, lorry 28 metric ton, fatty acid methyl ester 100%	CH	Transportation
13	Felipe Motta, Ecoinvent	Transport, freight, lorry 16-32 metric ton, EURO5 BR	RER	Transportation
14	Spielmann M., Ecoinvent	Transport, freight, inland waterways, barge RER	RER	Transportation
15	Gindroz F., Ecoinvent	Transport, freight train, electricity Europe without Switzerland	EUR	Transportation
16	Tereza Levova, Ecoinvent	Tap water production, conventional treatment Europe without Switzerland	EUR	Tap water

17	Hischier R., Ecoinvent	Sodium chloride production, powder RER	RER	Salt
18	PRé Consultants, Amersfoort, www.pre.nl	LDPE bottles E	RER	Plastic bag
19	PRé Consultants, Amersfoort, www.pre.nl	Oriented polypropylene film E	RER	Bread clip
20	Menard J.F, Ecoinvent	Aluminium around steel bi-metal wire production, 3.67 mm external diameter CA-QC	CA	Bread clip
21	Hischier R., Ecoinvent	Polyurethane production, rigid foam RER	RER	Label
22	Imbeault-Tétreault H., Ecoinvent	Containerboard production, fluting medium,	CA	Cardboard
23	Hischier R., Ecoinvent	Packaging film production, low density polyethylene RER	RER	Plastic film
24	Brunner, F., Ecoinvent	Electricity production, medium voltage, petroleum refinery operation RoW	RER	Oil
25	Spielmann, M., Ecoinvent	Transport, freight, inland waterways, barge RER	RER	Transportation
26	Gindroz, F., Ecoinvent	Transport, freight train, electricity Europe without Switzerland	RER	Transportation
27	Ecoinvent	Market for transport, freight, lorry with reefer, freezing GLO	GLO	Transportation
28	Hischier, R., Ecoinvent	Carton board box production service, with gravure printing CH	CH	Material recycling
29	Ecoinvent	Treatment of waste rubber, unspecified, municipal incineration Europe without Switzerland	RER	Energy production
30	Ecoinvent	Petrol, unleaded, burned in machinery	GLO	Petrol combustion

Appendix 2

Appendix 2 showing a list of the datasets used in SimaPro 9.4.0.2. Table 13 indicates data generator, name of dataset, geographic location and which process the datasets is used to model. Datasets are set to the Allocation, cut-off by classification.

Table 13. Datasets used in sensitivity analysis.

Number	Data generator	Dataset name	Location	Used to model
1	Blonk Agri-footprint BV	Wheat straw, at farm {SE} Economic, S	SWE	Rye cultivation
2	Blonk Agri-footprint BV	Rye grain, at farm {SE} Economic, S	SWE	Wheat cultivation
3	Blonk Agri-footprint BV	Rye grain, dried, at storage {FI} Economic, S	FIN	Rye cultivation
4	Nemecek, T., Ecoinvent	Wheat production, organic RoW	RoW	Organic cultivation
5	Nemecek, T., Ecoinvent	Rye production, organic CH	CH	Organic cultivation
6	Karin Treyer, Ecoinvent	Market for electricity, medium voltage SE	SWE	Electricity
7	Treyer, K., Ecoinvent	Market for electricity, medium voltage, renewable energy products CH	CH	Renewable electricity
8	Brunner, F., Ecoinvent	Electricity production, medium voltage, petroleum refinery operation RoW	RER	Oil
9	Moreno, E., Ecoinvent	Ethanol production from whey RoW	RoW	Bioethanol production
10	Ecoinvent 3	Petrol production, low-sulfur Europe without Switzerland	RER	Petrol production
11	Valebona F., Ecoinvent	Transport, freight, lorry 16-32 metric ton, EURO3 BR	RER	Transportation
12	Blonk Agri-footprint BV	Sow pig compound feed, at processing {NL} Economic, S	NL	Feed production
13	Ecoinvent 3	Market for rye grain, feed, Swiss integrated production CH	CH	Feed production
14	Valsasina, L., Ecoinvent	Market for transport, freight, lorry 28 metric ton, fatty acid methyl ester 100%	CH	Transportation

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