Determining the Cumulative Energy Demand and Greenhouse Gas Emission of Swedish Wheat Flour

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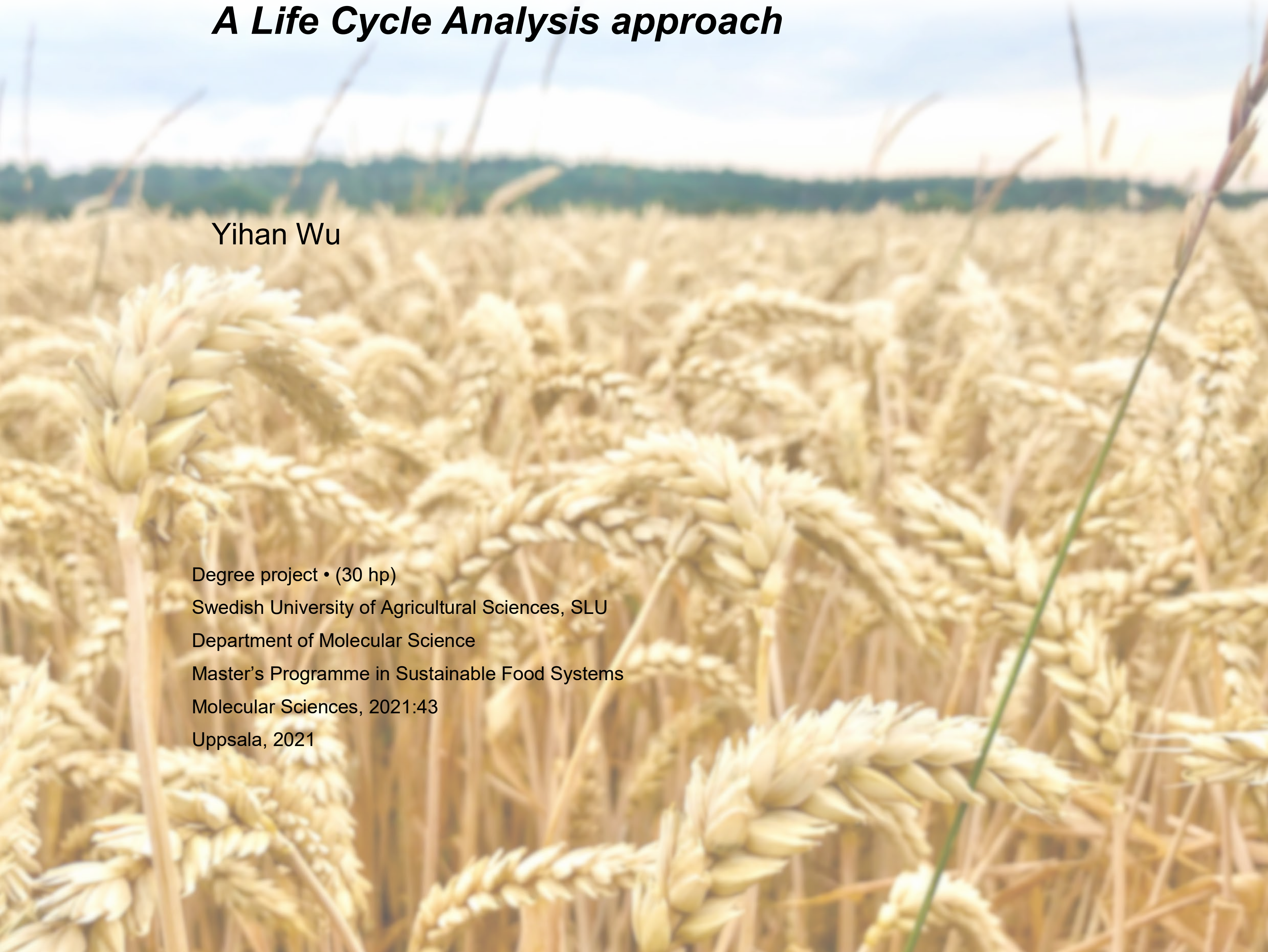
A Life Cycle Analysis approach



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Abstract

Food production brought a tremendous impact on human society. However, there has been a lot of debate between organic and conventional farming. Producing enough food by maximizing the yield to feed the growing population has been the main goal of agriculture nowadays. This goal is achieved by applying different kinds of synthetic chemicals to improve the performance of crops in conventional farming. However, this leads to different environmental problems like soil degradation, loss of biodiversity, and disruption of healthy ecosystems. As a result, there is a growing demand for information on the environmental impact of food products from consumers and food supply chain participants. The main objective of the current study is to investigate the environmental impacts of organic and conventional wheat flour produced and supplied in Sweden, using life cycle analysis (LCA) and focusing on the global warming potential (GWP) and cumulative energy demand (CED). A cradle-to-gate LCA with the functional unit (FU) of 1 ton of wheat flour at the gate of the milling facility is conducted in this study. The results of the present study show that in terms of GWP, conventional systems have a higher emission compared to organic systems. As to energy demand, the two systems have almost similar results. The GWP for the conventional systems is 356 CO_2-eq kg/FU while it is 249 CO_2-eq kg/FU for the organic systems. The CED for the conventional system is 4025 MJ/FU while it is 3983 MJ/FU for the organic system. The farm activity is the hot spot stage for both conventional and organic systems. Overall, when considering environmental aspects, wheat flour from organic farming in Sweden is more sustainable than wheat flour from conventional farming systems. Increasing the yield for organic farming could improve further the environmental sustainability of organic wheat flour.

Keywords: Energy demand, Greenhouse gas emission, Global warming potential, Life cycle analysis, Organic farming, Conventional farming

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Abbreviations

CED	Cumulative Energy Demand
GHG	Greenhouse Gas
GWP	Global Warming Potential
FiBL	Research Institute of Organic Agriculture
FU	Functional Unit
IFOAM	International Federation of Organic Agriculture Movements
LCA	Life Cycle Analysis
SCB	Statistics Sweden

1. Introduction

1.1. Background

There has been a lot of scholarly debate between organic and conventional farming. Food production brought a tremendous impact on human society. Producing a sufficient amount of food by maximizing the yield to feed the growing population has been the main goal of conventional agriculture (Robinett, 2015). However, this goal is achieved by applying different kinds of synthetic chemicals to improve the performance of the crops which can lead to different environmental problems like soil degradation, loss of biodiversity, and disruption of healthy ecosystems (ibid).

In 2020, the agricultural sector accounted for 1.3% of the total EU-27 gross domestic product (Eurostat, 2020). At the same time, agriculture is using 48% of the land in Europe (European Commission, 2020). Therefore, the impact of agriculture on the environment should not be underestimated. According to European Commission (2020), agriculture contributed 92% of total ammonia (NH_3) emissions in the European Union. Moreover, more than 50% of the freshwater was used in agriculture which is higher than all of the rest put together (ibid.). As a result of these environmental issues, there is a growing demand for information on the environmental impact of food products from consumers and food supply chain participants (Peng, 2019). In this regard, organic food production is gaining increasing attention. According to the International Federation of Organic Agriculture Movements (IFOAM), organic agriculture is defined as

> *A production system that sustains the health of soils, ecosystems, and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic Agriculture combines tradition, innovation, and science to benefit the shared environment and promote fair relationships and good quality of life for all involved (IFOAM, 2008).*

Organic farming is based on using natural materials and avoiding synthetic chemicals to sustain soil fertility and eco-balance to decrease and eliminate negative impacts such as soil degradation and eutrophication that are caused by conventional farming (ibid).

1.2. Organic Farming in Sweden

In Sweden, there are different labelling systems for organic products. The most well-known are the KRAV-certified and EU organic green leaf (FiBL, 2018). KRAV was the dominant company that certified organic production in Sweden until 2006 (Clarin et al., 2010). Nowadays, KRAV is used on more than 80% of the organic product in Sweden ((FiBL, 2018).). In 2007, SMAK and Aranea Certification were granted for organic certification, and in 2008 HS certification was added. In addition, there is Valiguard, which controls processed foods and imported products. EU organic green leaf certification is compulsory for all organic products whereas the KRAV label is voluntary. Compared to the EU label, KRAV has stricter rules and higher standards for organic products, especially for animal welfare, environment, and health, and better working conditions (FiBL, 2018).

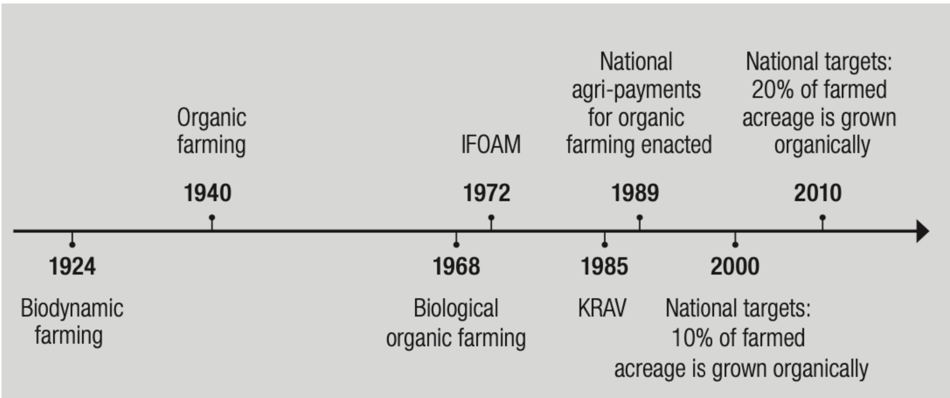

Figure 1 The growth of Swedish organic farming (Kirchmann et al., 2016, p.30)

This figure describes the growth of organic farming in Sweden from 1924-2010.

In 2019, 614,300 hectares of agricultural land were cultivated with organic production methods in Sweden, which is an increase by 18% compared to 2015. According to a report from the Research Institute of Organic Agriculture FiBL and IFOAM, Sweden is one of the leading countries in terms of organic farming. The share of organic land compared to conventional land in Sweden is 20.4% which is 40% more than ten years ago (Jordbruksverk, 2015a & 2019). Furthermore, the number of companies with organic crop production increased by almost 400 companies since 2015 and amounted to 5,700 in 2019 (ibid).

There are two main reasons for farmers to transfer to organic farming. The first one is to enhance economic profit since organic products normally have a higher price compared to conventional products. The second reason is to avoid and decrease chemical synthesis in the production (Jordbruksverket, 2015b). The major shift to organic milk and egg production in recent years has created a great demand for organic cereals, bovine grains, oilseeds, and grass seeds (ibid.). Organic crops have a relatively lower yield compared to conventional ones. For example, as illustrated in Figure 2, the yield in organic cereals, oilseeds, and grass seeds is 30 to 50% lower compared to conventional ones (Kirchmann et al., 2016). However, this difference is offset by the fact that farmers get paid more for the products, receive environmental subsidies for the crops, and have lower input costs (Jordbruksverket, 2015b).

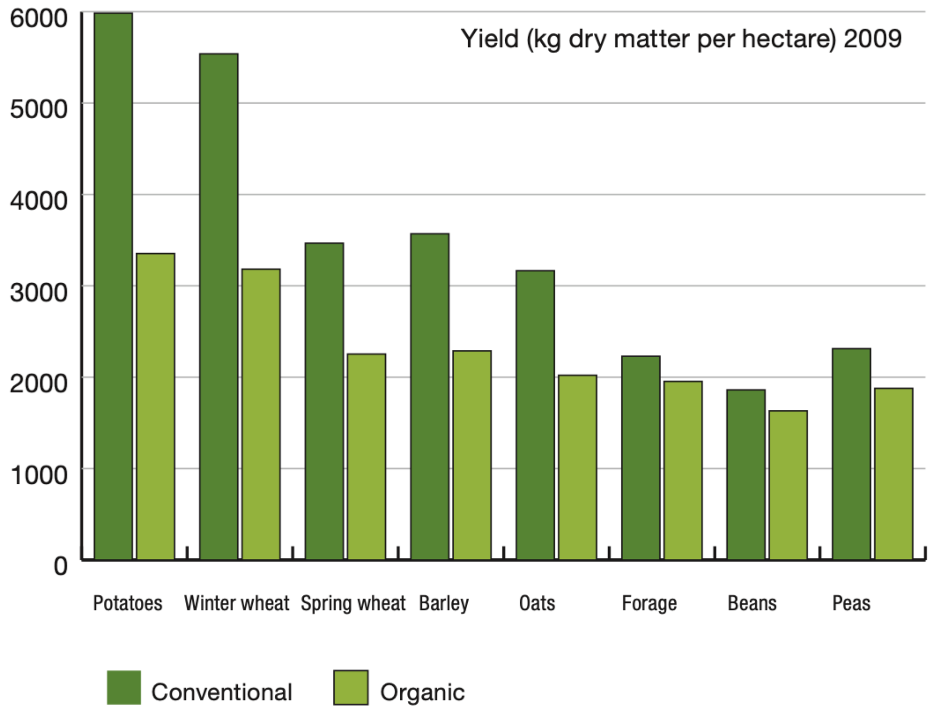

Figure 2 Yield difference between organic and conventional farming (Kirchmann et al., 2016, p.41)
*Dry matter: the grains that are harvested and dried, water content <16%

The price of organic products is often 30 to 50% higher (Kirchmann et al., 2016). The subsidies for switching to certified organic production are paid annually, 1500 krona/ha for cereals, oilseeds, and other kinds of crops, and 5000 krona/ha for potatoes and vegetables (Jordbruksverket, 2015b). Farmers receive subsidies for agreeing to start a 5-year commitment for organic cultivation. However, at the beginning of the first two years, even though the products will be produced organically, they will be labelled as conventional (ibid.). Lindström et al. (2020) concluded in their study that organic subsidies and organic farmland are positively correlated. The study also suggests that increasing organic food purchases of the public sector can have a positive impact on increasing organic farmland as well. Recently, the Swedish government set a new target to increase certified organic agricultural land by 30% and increase public consumption of certified organic food by 60% by the year 2030 (Näringsdepartementet, 2017).

Given the fact that organic farming has lots of advantages in terms of environmental protection, animal welfare, and human health (Kirchmann et al., 2016), it seems like switching to organic is the right thing to do. However, organic farming also has its disadvantages. First of all, switching to organic farming is not easy. The low productivity due to lower yields, lower animal density, higher labour intensity can cause extra costs for farmers (Tranter et al., 2009). Moreover, when the weather is tough, there is a possibility that the farmers can lose their entire crop and have zero yields for the year (ibid). Meanwhile, Tuomisto et al. (2012a) conclude that products from organic agriculture tend to have higher NH_3 emissions, nitrogen (N) leaching, and Nitrous oxide (N_2O) emissions due to extensive use of organic fertilizer. Moreover, even though organic farming requires less energy input, because of the lower yields, it demands more agricultural land to grow crops which can lead to higher energy use per unit (ibid). Although customers are willing to buy organic products because it uses fewer synthetic chemicals, they may not have the full information about the environmental effect that is caused by producing and transporting the organic products (ibid). Therefore, it is important to analyse the outcomes caused by conventional and organic farming to improve the current agriculture system.

1.3. Wheat Cultivation

Wheat is one of the most important food crops in the world (FAOSTAT, 2021). The most grown wheat species nowadays is called common wheat or bread wheat. Among all the crops, wheat has the highest area harvested (ibid). In 2019, roughly 765 million tonnes of wheat were produced all over the world, accounting for 25% of the total cereal production and 8% of the total crop produced (ibid). In Sweden, the average yield of conventional winter wheat from 2014 to 2018 was 6900kg/ha and 3990kg/ha for organic winter wheat (SCB, 2019a). In Europe, the United Kingdom has the highest yield of wheat production which is 8400kg/ha on average in the last five years (National Statistics, 2020). The global yield of wheat in general is about 3400kg/ha on average (FAOSTAT, 2021). The reason for only considering winter wheat in the current study is because the spring wheat in Sweden accounts only for 10% of the total wheat area (SCB, 2019b). Spring wheat is normally planted around spring and harvested in autumn. Before, spring wheat was dominant for a long time. But because it requires more nitrogen to reach a good protein content, thus using more fertilizers makes profit low (Jordbruksverket, 2018).

Winter wheat is normally planted in the autumn and harvested around summer. By doing so, the wheat can take advantage of the autumn rain and germinate (Jordbruksverket, 2018). During the winter, it stays in its vegetative phase and starts growing again at the beginning of spring. The winter snow can protect the young plants from freezing. Compared to spring wheat, winter wheat requires less irrigation and has a higher yield (Curtis et al., 2002). In Sweden, wheat is mainly produced in the southern and central parts of the country, and most of the wheat is milled into flour for further purposes like pasta and the remaining is exported to other countries (SLU, 1995).

The wheat cultivation in Sweden accounts for one third of the total agricultural land, and it is also the most grown cereal in Sweden. There are reasons for such a big expansion: better tilling technology, better wheat hybrids, and higher living standards (Nationalencyklopedin, 2020).

At the agricultural production stage, the main activities include: Harrowing (breaking up and smoothing out the surface of the soil); Tilling (for use in between individual rows of crops); Ploughing (loosening or turning the soil before sowing seed); Sowing (planting the seed); Weed management; Fertilizers/pesticides management; Irrigation management; and harvesting. Similarly, the main post-harvest activities include storage, transport, drying the wheat, and milling (Kumar, 2009).

Tillage is a common term to use when talking about machine operations in the field. Tillage includes all the operations before sowing seeds like ploughing and harrowing. The word tilling in the current study only refers to the act of using tiller which is for working on individual rows rather than several rows like harrowing. Harrowing means working on the deeper layer of the soil and tilling is for the upper layer (Van Oost et al., 2006).

As for organic wheat cultivation, there is no application of any artificial pesticides or fertilizers. To have a higher yield, farmers usually have crop rotation with green manure like legumes or using animal manure to fertilize the soil. An example of crop rotation is indicated in Table 1 (Sonesson et al., 2009):

Table 1 Example of crop rotation to increase wheat yield (Sonesson et al., 2009)

Year	Crop
1	Oats
2	Peas
3	Winter rapeseed

4	Winter wheat
5	Forage lay
6	Winter wheat
7	Field beans

Leguminous plants like peas and beans are important in organic farming (ref.). They provide the essential nutrients that soil needs by fixing the nitrogen in the atmosphere to the soil. Normally the legumes used for green manuring can accumulate 80 to 100 kg/ha of nitrogen in 45 to 60 days of growing (Meena et al., 2018). According to Statistics Sweden (SCB) (2020), in the year 2018/19, 161kg /ha of nitrogen was used for conventional winter wheat in Sweden. In both conventional and organic production systems of wheat, assessing the environmental impact is important. In the current study, LCA approach was used to address this.

1.4. Life Cycle Analysis

LCA is a tool to "assess environmental impacts associated with all the stages of a product's life" (Muralikrishna & Manickam, 2017, p.57). In this study, the author uses LCA as a method to analyze and compare global warming potential (GWP) and cumulative energy demand (CED) of organic and conventional wheat production in Sweden.

> LCA considers the entire life cycle of a product, from raw material extraction and acquisition, through energy and material production and manufacturing, to use and end of life treatment and final disposal. Through such a systematic overview and perspective, the shifting of a potential environmental burden between life cycle stages or individual processes can be identified and possibly avoided (ISO 14040, 2006).

There are two main purposes of an LCA study. The first one is to analyze the environmental impact of each life cycle stage in order to improve the process of production. The second one is to compare different products (Muralikrishna & Manickam, 2017). An LCA study normally has four different stages (Figure 3):

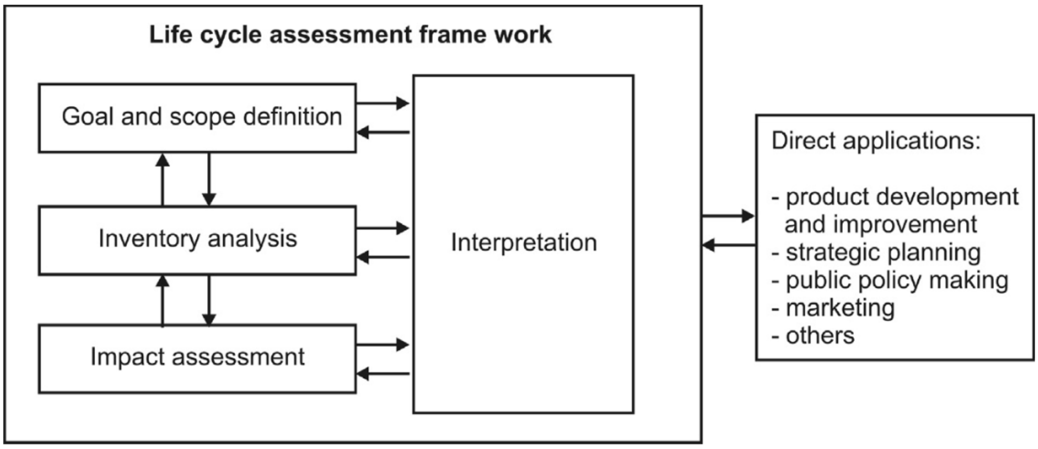

Figure 1 The four stages of a LCA according to ISO 14040 (2006, p.58)

Figure 3 depicts the four stages inherent to a LCA. These stages are:

1. Goal and scope definition: to define the aim and intended application of the study. System boundary and functional unit (FU) are normally introduced in this section. The system boundary is to determine the process that is included in the study, i.e., production of fertilizer or transportation. FU is a basic unit for calculation.

2. Inventory analysis: to describe the material and energy input and output of the system.

3. Impact assessment: to present the details from the inventory analysis and describe the results of all impact categories.

4. Interpretation: to interpret and present the outcome of the LCA study with critical review and determine the data sensitivity.

An LCA study is generally based on quantitative data to build the material and energy flow of a production system in order to observe the interaction between system and environment. A model is built in the phase of inventory, and the results are normally presented in a linear way or as a process tree including the chosen process (Muralikrishna & Manickam, 2017). According to Williams et al. (2006), there are several main sources that can be the cause of environmental impacts in the crop production regardless of conventional or organic production methods. These include: 1) the use of diesel for fertilizers and pesticide application, field irrigation, and harvesting; 2) production of fertilizers and pesticides; 3) energy that is used for drying or cooling the crop; 4) N soil emission; v) land use.

The main objective of this study is to evaluate the greenhouse gas (GHG) emission and cumulative energy demand (CED) of conventional and organic wheat flour supply chains.

1.5. Research Questions

In this study, it was aimed to address the following research question:

1. What is the environmental impact (CED and GHG emission) of wheat production, processing, and flour supply in Sweden?
2. What are the environmentally hot-spot stages in the life cycle of the wheat flour supply chain?

2. Literature Review

In this chapter, the results and discussions of previous studies regarding the GWP and energy use of both organic and conventional wheat production are presented. The literature encompasses studies from different geographic areas. The first section presents Swedish organic and conventional wheat farming. The second section portrays studies from other European countries such as Italy, UK and Norway. The last section presents literature from countries outside of Europe such as US, Canada, and China.

2.1. Sweden

Stadig et al. (1999) conducted an LCA to compare the environmental impact of organic and conventional wheat flour. According to Nilsson (2006) and Florén et al. (2006), who referred to the work of Stadig et al (1999), the wheat that is used in the study is from Västergötland which is located in the south of Sweden. The system boundary includes machine use, fertilizers, pesticides, production of fertilizers, and plant-related emissions. The functional unit of the study was 1kg of wheat flour produced. In the study, 1212 kg of wheat is used to produce 1000kg of wheat flour for both the conventional and the organic raw material. The main difference between conventional and organic cultivation in their study is that the conventional farms apply artificial fertilizers and pesticides to the crops whereas the organic farms apply raw phosphate and use crop rotation with green manure crops at the same time. The study found that yields from the organic farms account for 54% of the yields from the conventional ones, which means that the land use was almost twice as high per kg of wheat flour for organic cultivation. For every kg of conventional wheat flour, 1.7 m^2 of land is used, and for every kg of organic wheat flour, 3.3 m^2 of land is used (Florén et al., 2006). Moreover, the land use per kg of organic wheat flour increases to 3.8 m^2/kg if the land use for crop rotation is taken into consideration. The main cause for such low yields is the low application of nitrogen (Nilsson, 2006). The total GHG emission of organic wheat flour is 353g CO_2 -eq/functional unit, and 540g CO_2 -eq/functional unit for conventional wheat flour (Florén et al., 2006). According to Nilsson (2006), the GHG emissions in conventional farms are mainly from the burning of fossil fuels and the natural gas that is used in the production of fertilizers. And for the organic system, the main causes are emissions from nitrous oxide and machinery use. Meanwhile, according to Florén et al. (2006), the energy use for producing conventional wheat flour is 1.42 MJ/kg flour and 2.25MJ/kg flour for organic ones which is 63% of the conventional ones.

Sonesson et al. (2009) conducted a comparative study between organic and conventional animal feed in Sweden regarding GHG emissions. The study shows that conventional farming and organic farming have similar GHG emissions. For organic winter wheat with green manuring, the GHG emission is 440g CO_2 -eq/kg wheat. And for conventional winter wheat, the GHG emission is 443g CO_2 -eq/kg wheat. The emission of CO_2 represents roughly 30% of the total emission and the emission of N_2O accounts for roughly 65%. Diesel and oil use account for roughly 50% of the total CO_2 emission, and production of fertilizers accounts for 35%. Meanwhile, emission from the soil directly is 55% of the total N_2O emission, emission of fertilizer production represents 35%. Sonesson et al. (2009) suggest that using fertilizers and diesel more efficiently can help to reduce the environmental impact of both organic and conventional wheat production.

Kirchmann and Bergström (2008) analysed the limitations of organic crop production. They compared the energy use of organic and conventional farming with two different scenarios. The first one is with animal products in the system, and the second is without. The reason for this is that the nutrient circulation through animals and nitrogen fixation through plants can have a great impact on the two different systems. As shown in Table 2, both conventional systems have much higher energy input compared to organic systems. This is mainly because conventional systems apply N fertilizer to the crop. However, according to Jenssen and Kongshaug (2003), the energy use in modern fertilizer factories is roughly 38MJ/kg N. So, Kirchmann and Bergström use this figure instead of 42 MJ/kg N to calculate the energy use in a conventional system. The result shows that the energy use in conventional systems decreases massively, and it is almost the same as in organic systems.

According to Kirchmann et al. (2016), the energy output created by using N fertilizer is 8 to 15 times more than used in producing the N fertilizer. Therefore, they believe that using N fertilizer is an energy-positive activity, thus it is worth using nitrogen fertilizer because of the benefits it brings to us (Figure 4).

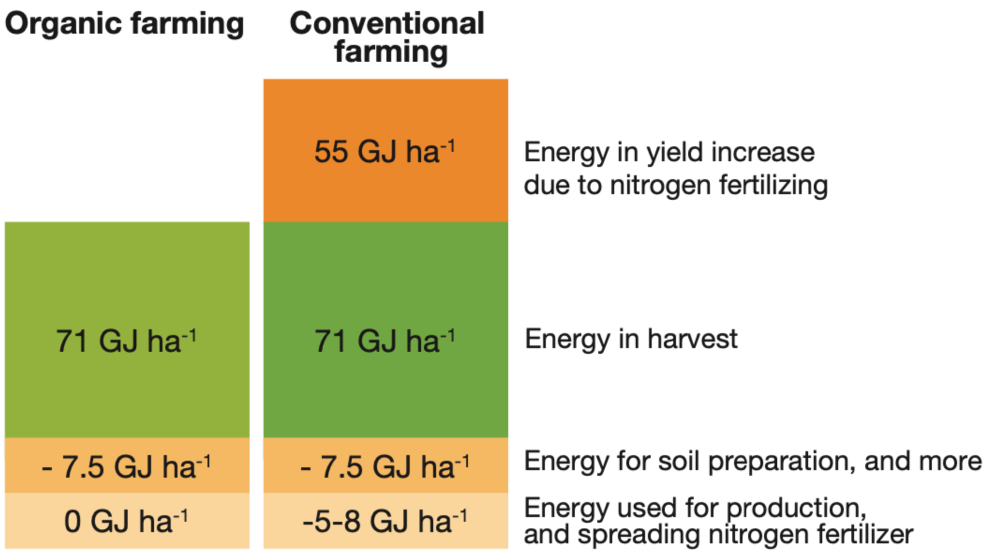

Figure 2 Energy balance (GJ/ha) between conventional farming and organic farming (Kirchmann et al. 2016. p.92)

Cederberg et al. (2011) conducted a study to analyze the climate footprint of organic agricultural products in southern (Skåne), western (Västra Götaland), and eastern (Östergötland-Mälardalen) Sweden. As shown in Table 2, the GHG emission of organic wheat, in this case, is quite low (280g CO_2 -eq/kg). The authors explain that is mainly because of the relatively high yield. The crop accepted Biofer (organic fertilizer) instead of green manure, and the carbon footprint is 75% of the conventional winter wheat.

Several studies conclude that the main contributions to the GHG emission in conventional farming are the fertilizer production and the emission of N_2O and ammonia from soil (Röös et al., 2011; Bernesson et al., 2006; Tidåker et al., 2007). According to Röös et al. (2011), the mean GHG emissions of 1 kg of wheat which comes from one representative farm in the region of Skåne before milling is 310g CO_2-eq/kg. However, the actual values range from 220g-560g CO_2-eq/kg. The reason for causing such a big range is the consequence of the N_2O emission from soil which is extremely complicated (ref.) (See Table 2).

Table 2 Findings (emission and energy use) of previous LCA studies in Sweden (author's own compilation)

System boundary and FU	System	GHG emissions	Energy use	Reference
Organic and conventional wheat flour production (including fertilizers and	Org*	353g CO_2 -eq/FU	1.42 MJ/kg flour	Florén et al. (2006),

pesticides production and transportation) FU: 1 kg of flour	Con**	540g CO_2 -eq/FU	2.25 MJ/kg flour	Nilsson (2006)
Organic and conventional feed wheat production (including fertilizers and pesticides production and transportation) FU: 1 kg of grain	Org	440g CO_2 -eq/kg wheat		Sonesson et al. (2009)
	Con	443g CO_2 -eq/kg wheat		
Organic and conventional wheat production (including fertilizers and pesticides production)	Org		5812.9 MJ/ha	Kirchmann & Bergström (2008)
	Con		10337.3 MJ/ha	
Organic and conventional wheat production with animal production systems (lay and manure) FU: 1 ha of wheat	Org (animal)		5885.4 MJ/ha	
	Con (animal)		13358.7 MJ/ha	
Cradle to gate FU: 1 kg of wheat	Org	280g CO_2 -eq/kg		Cederberg et al. (2011)
Cradle to retail FU: 1 kg of wheat before the milling process (primary production)	Con	310g CO_2 -eq/kg wheat before the milling process		Röös et al. (2011)
Cradle to gate	Con	2210kg CO_2 -eq/ha	13.1 GJ/ha	Bernesson et al. (2006)
All activities related to yearly grain production (Conventional) FU: 1 kg of winter wheat harvested	Con	467g CO_2 -eq/FU	1.8 MJ/FU	Tidåker et al. (2007)

*_Organic; **_Conventional

To summarize, the GWP for organic wheat systems is from 280 CO_2-eq/kg to 440 CO_2-eq/kg wheat. And the GWP for conventional wheat systems is from 310 CO_2-eq/kg to 467 CO_2-eq/kg wheat. The energy use for organic wheat systems is from 1420 MJ/t to 1680 MJ/t wheat, and the energy use for conventional wheat systems is form 1660 t/kg to 1900 MJ/t wheat.

2.2. Europe

Tuomisto et al. (2012b) compared GWP and energy use of five different winter wheat farming systems in the UK. As shown in table 3, the first farming system is the organic farming system without biogas production (Org) which combines grass-clover, cover crop, and crop residues for fertilizing the soil. The second one is an organic farming system with biogas production (OB) that harvests the grass-clover, cover crop, and crop residues to produce biogas. The third one is conventional farming (Con) with mineral fertilizers and non-organic pesticides. The fourth one is an integrated farming system (IF) that is similar to the OB but using non-organic pesticides. The last one is the special integrated farming system (IFS) which uses municipal biowaste as fertilizer instead of grass-clover. Additionally, ploughing is used in all five systems. The result of the study shows that the IFS system has the best performance in terms of low energy use and low GWP per FU. The authors pointed out that replacing artificial N fertilizer with municipal biowaste or green manure and decreased machinery use in the field can significantly reduce energy use. Meanwhile, increasing yields, applying nitrification inhibitors, and replacing artificial N fertilizer are important for reducing GWP. The study concludes that combining organic and conventional farming can potentially decrease the negative impact on the environment.

Alhajj Ali et al. (2016) established a 5-year field experiment from 2009 to estimate the GHG emission of wheat-faba bean rotations under different crop management. They compared 12 different scenarios which are conventional (Con), reduced tillage (RT), and no-tillage (NT) with 4 different nitrogen fertilizer application plans (0, 30, 60, 90kg/ha of N). As shown in Table 3, the NT systems have the lowest GHG emission, meanwhile, it is said that the NT systems have the highest yield on average compared to the other two systems. The authors explain that it is because the plant residues that are left on the field increase the quality of soil, and with the rotation of faba bean more nitrogen is available for wheat growth. Alhajj Ali et al. (2016) believe that the tillage system has the main contribution to GHG emission because of the amount of diesel fuel that is used. The authors suggest that the best way to decrease GHG emissions is to reduce the use of nitrogen fertilizer as well as tilling and apply plant rotation to compensate for the nitrogen lack.

Similarly, Knudsen et al. (2014) and Rajaniemi et al. (2011) both conclude that the use of diesel fuel for tilling and fertilizer use in the field are contributing the most in terms of negative environmental impact. Knudsen et al. (2014) suggest that combining rotation system with legumes can be helpful for yields and lower the emission at the same time. Additionally, they also noticed that ferment the legumes that are harvested from the field to produce biogas and use the residues for fertilizing can be even more helpful than just using them as green manure.

Korsaeth et al. (2014) analyzed cereal production (barley, oats, and wheat) based on the different climates in Norway. The result showed that field emission contributes more than half to the total GWP. They noticed that level of soil organic carbon (SOC) in agricultural land at higher latitudes has a significant effect on the GWP of the grain production chain. When SOC reaches 4%, the emission from the field accounts for more than the rest of the sources combined in the production chain for grains (see Table 3).

Table 3 Some of the findings (emission and energy use) of previous studies in Europe (author's own compilation)

System boundary and FU	Systems	GHG emissions	Energy use	Country	Reference
The production of farming inputs and machinery, farming operations and crop cooling and drying FU: 1ton of wheat with 86% of DM	Org	367 kg CO_2eq/t	1705 MJ/t	UK	Tuomisto et al. (2012)
	OB	366 kg CO_2eq/t	2308 MJ/t		
	Con	401 kg CO_2eq/t	1618 MJ/t		
	IF	310 kg CO_2eq/t	1389 MJ/t		
	IFS	183 kg CO_2eq/t	695 MJ/t		
	Con	2991 kg CO_2eq/ha			
Cradle to gate FU: 1ha of wheat	Con	1614.5kg CO_2eq/ha		Italy	Alhajj Ali et al. (2016)
	RT	1564.6kg CO_2eq/ha			
	NT	1264.2kg CO_2eq/ha			
Cradle to gate FU: 1kg of harvested crop DM	Mulching	283 kg CO_2eq/t		Denmark	Knudsen at al. (2014)
	Biogas	-65 kg CO_2eq/t			
	No input	409 kg CO_2eq/t			
	Slurry	287 kg CO_2eq/t			
	Con	379 kg CO_2eq/t			
Cradle to gate FU: per kilogram grain	Con	2330 kg CO_2eq/ha		Finland	Rajaniemi et al. (2011)
	RT	2250 kg CO_2eq/ha			
Cradle to gate FU: per kg grain with 85% DM	Con	0.5–0.9kg CO_2eq/ha		Norway	Korsaeth et al. (2014)

To summarize, the GWP for organic wheat systems is lower than 400 CO_2-eq/kg wheat. And the GWP for conventional wheat systems is from 380 CO_2-eq/kg to 401 CO_2-eq/kg wheat. One thing that is worth mentioning is that tillage is also a notable contributor to GHG emission. Based on the study from Alhajj Ali et al. (2016), the cultivation with no tillage reduced the GHG emission by more than 20%.

2.3. Outside of Europe

Meisterling et al. (2009) conducted an LCA to compare the GWP and energy use for organic and conventional production chains of wheat in the United States. In their study, it is clear that the conventional wheat production chain has a higher GWP and energy use when both are transported with the same distance. However, they noticed that there is little difference of negative environmental impact between organic and conventional wheat when transporting organic wheat more than 420km by train or truck. Therefore, they suggest that finding an alternative way of transport mode could be helpful regarding decreasing GWP and energy use.

Pelletier et al. (2008) concluded from their LCA study in Canada that synthetic fertilizer production for conventional farming is the main contributor to energy use (62%) and the second contributor to global warming (31%). But for organic farming, fuel is the main source of energy use (66%). Meanwhile, field emissions from fertilizer account for the most regarding global warming for both conventional (50%) and organic farming (66%).

In Australia, Biswas et al. (2008) conducted an LCA to measure the GWP of wheat production from cradle to port when wheat is exported. In their study, they divided the production chain of wheat into three different stages which are pre-farm, on-farm, and post-farm. According to their study, the pre-farm stage accounts for the most impact in terms of total GWP which is 45% followed by the on-farm stage which is 44%, and the post-farm stage which is 11%. The production and application of nitrogen fertilizer contribute the most to GWP in the pre-farm and on-farm stages. For the post-farm stage, transportation is contributing the most to GWP. Therefore, the authors suggest that finding a better way of producing fertilizer and cleaner fuel for transporting wheat can effectively decrease the GWP of wheat production.

Taki et al. (2018) compared the rainfed and irrigated wheat production in Iran through LCA. They found out that because of lower yield, rainfed wheat has higher GWP compared to irrigated wheat. But the energy input for rainfed wheat is significantly lower than the irrigated one. However, the energy output in the rainfed systems and irrigated systems are similar (132.63 and 133.50 kg/GJ).

In terms of irrigated system, researchers from China use LCA to analyze the emission of winter wheat production chain in northern China (Wang et al., 2016). They found out that the electricity for irrigation contributes the most to the emission, followed by nitrogen fertilizer, phosphate fertilizer, and direct nitrogen emission from soil (See table 4).

Table 4 Some of the findings (emission and energy use) of previous studies outside Europe

System boundary and FU	Systems	GHG emissions	Energy use	Country	Reference
Cradle to retail FU: 0,67 kg of wheat flour	Org	300 g CO_2eq/FU	2700 J/FU	US	Meisterling et al. (2009)
	Con	330 g CO_2eq/FU	3300 J/FU		
Cradle to gate FU: 1 kg of grain	Org	290 g CO_2 -eq/kg	0.8 MJ/kg	Canada	Pelletier et al. (2008)
	Con	382 g CO_2 -eq/kg	2.7 MJ/kg		
Cradle to port FU: 1 ton of wheat	Con	303 kg CO_2eq/t		Australia	Biswas et al. (2008)
Cradle to gate FU: 1 ton of wheat	Rainfed	380 kg CO_2eq/t	9.35 GJ/ha	Iran	Taki et al. (2018)
	Irrigated	317 kg CO_2eq/t	23.41 GJ/ha		
Cradle to gate FU: 1kg of wheat		2900-4590 kg CO_2eq/ha		China	Wang et al. (2016)

In general, almost all the literature above agree that conventional systems have a relatively larger impact on environmental sustainability compared to organic systems in wheat production. And the main reasons are the use of nitrogen fertilizer, the use of fuel in field machinery as well as the field emission during the tilling process. In terms of organic systems, fuel use and field emission are also the main causes for negative environmental impact.
The reason the author including these findings from the literature is to present the current situation regarding wheat cultivation around the world and especially in Sweden. There are a few reasons for doing the current study. The first is that most of the previous studies did not focus on only wheat cultivation, rather on different crops including wheat. The second reason is that most studies were completed 10 to 20 years ago, so they may no longer be applicable to the current situation. The last reason is that most studies are done in Swedish, therefore, it is hard to understand for non-Swedish researchers. The current study wishes to contribute more accurate information to organic and conventional wheat cultivation in terms of GHG and energy use for further studies.

3. Methodology

3.1. Goal and Scope

3.1.1. Goal

The goal of this LCA is to analyze the environmental impacts of organic and conventional wheat flour produced and supplied in Sweden, focusing on GWP and primary energy use impact categories. The specific objectives are:

- to find out the environmental hotspot stages along the wheat flour value chain.
- to compare, from the environmental point of view, the wheat flour from the conventional and organic production systems.

3.1.2. Scope

This LCA analyzes two different scenarios:

- Conventional wheat flour supply chain
- Organic wheat flour supply chain

Functional Unit

The functional unit of this LCA is 1 kg of wheat flour that is ready for further processing.

System Boundary

This is a cradle-to-gate LCA. It includes all the farm activities and factory processes to produce wheat flour (see Figure 5). However, some processes such as the production of machinery, land use, construction of buildings, and direct soil emission are excluded.

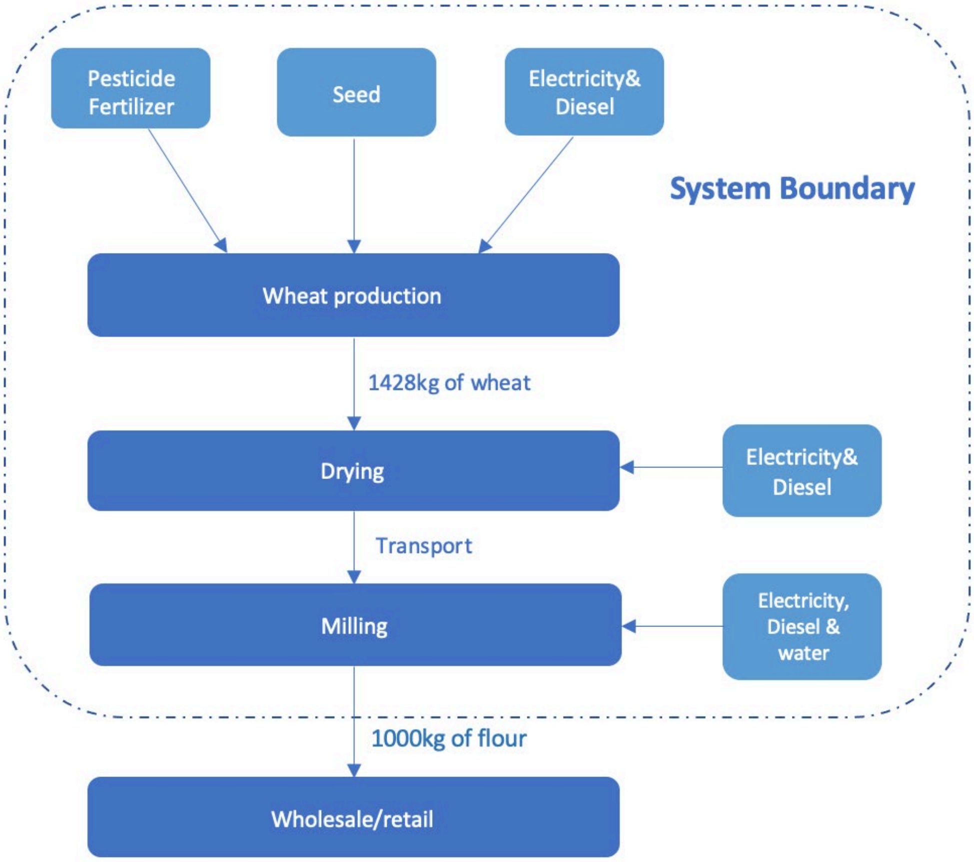

Figure 3 System boundary (author's own compilation)

Impact category

The impact categories of global warming potential (GWP) and cumulative energy demand (CED) have been investigated. SimaPro 9.0, a program for calculating LCA, is used for the calculation.

Allocation

All environmental burden is allocated to the flour and no by-product is included due to lack of data.

Assumption and Limitation

Since most of the wheat in Sweden is produced in the South of the country, the location of the project is based on the same assumption. The distance between farm and mill is assumed as 100km. Sweden does not produce commercial fertilizers, and most of the nitrogen, phosphate, and potassium (NPK) fertilizers are imported from Finland (Ahlgren et al., 2011). Therefore, it is assumed that the fertilizers used in the conventional system in this study are imported from Finland through the port in Gothenburg and transported by truck to the farm. The distance from port to farm is assumed to be 100km. The environmental impact of shipping from Finland to Sweden is not included in this case. Similarly, most of the pesticide's plants are concentrated around Gothenburg and Stockholm, therefore the distance for transporting pesticides is also assumed as 100km. The lubricating oil used in machinery is omitted.

The limitation of the project is that the data that are collected are a bit old. However, it is the best the author can find. For example, the diesel used in the field for machinery is from 2002, and input data for milling is from 2007. It is certain that there is an improvement since then regarding the diesel use efficiency.

3.2. Life Cycle Inventory

The data is mainly collected through literature and the Swedish statistics database (SCB and Jordbruksverket). The yields of both conventional and organic wheat are the average of the whole of Sweden from 2014 to 2018. The extraction rate for producing one ton of wheat flour is around 70% (Atwell & Finnie, 2011). Therefore, when calculating the input data, 1428kg of wheat is used.

The whole wheat supply chain is divided into three main parts. The first part is the farm activity. It includes the fertilizers and pesticides used in conventional farming and green manure use in organic farming. It also includes the diesel for all the machinery activities in the field like plowing, sowing, fertilizing, and harvesting. The details are displayed in Appendix I. Drying is assumed to happen on the farm therefore the electricity used for drying is also included under farm activity. In most cases, the water content in newly harvested wheat is 18%, it decreases to 14% after drying. The study does not consider the weight difference of wheat before and after drying since it is not significant.

The second part is the milling process, which contains the use of electricity and natural gas for milling the grains. The last part is transportation. It is assumed that the fertilizers used in the conventional system in this study is imported from Finland through the port in Gothenburg and transported by truck to the farm. The distance from port to farm is assumed to be 100km. The environmental impact of shipping from Finland to Sweden is not included. Similarly, most of the pesticide's plants are concentrated around Gothenburg and Stockholm, therefore the distance for transporting pesticides is also assumed as 100km. Since all the data collected are from the farms in the south part of the country, and the mill is also assumed to be in the south, therefore, the distance between farm and mill is assumed to be 50km. For organic system, due to the absence of pesticides and fertilizer, only the distance from farm to mill is considered. The packaging and lubricating oil used in machinery is not included in this study. See table 5and 6for details.

Table 5 Input data: Conventional wheat flour

Process	Unit*	Quantity	Comment	Source
Yield	kg/ha	6900	Winter wheat 6900kg/ha	(SCB, 2020)
Wheat required for 1t flour	kg	1428		(Atwell & Finnie, 2011)
Farm Activity				
Fertilizer use				(SCB, 2020)
N	kg	33.32	161 kg/ha	
K	kg	10.14	49 kg/ha	
P	kg	4.32	21 kg/ha	
Pesticides use	kg	0.24	1.2 kg/ha	(Röös et al., 2011)
Seed use	kg	37.25	180 kg/ha	(Röös et al, 2011)
Field diesel**	MJ	400	52.5L/ha	(Lindgren et al., 2002) (Flysjö et al., 2008)
Electricity for drying	MJ	62	300 MJ electricity/ha	(Röös et al, 2011)
Milling				(Bevilacqua et al., 2007)
Electricity	Wh	0.08		
Natural gas	J	11.4		
Transport				(Google map, 2021)
Fertilizer	tkm	4.778	100km	
Pesticide	tkm	0.024	100km	
Farm to mill	tkm	71.4	50km	

**Unit is per FU unless indicated specifically*
***Details are in Appendix I: Machinery activity*

Process	Unit*	Quantity	Comment	Source
Yield	kg/ha	3990	Winter wheat: 3990 kg/ha	(SCB, 2020)
Wheat required for 1t flour	kg	1428		(Atwell & Finnie, 2011)
Farm activity				
Green manure	ha	0.357		(Ecoinvent 3, year?)
Seed use	kg	64	180 kg/ha	(Röös et al, 2011)
Field diesel**	MJ	620	47 l/ha	(Lindgren et al., 2002) (Flysjö et al., 2008)
Electricity (drying)	MJ	107.37	300 MJ electricity/ha	(Röös et al, 2011)
Milling				(Bevilacqua et al., 2007)
Electricity	Wh	0.08		
Diesel	J	11.4		
Transport				(Google map, 2021)
Farm to mill	tkm	71.4	50km	

Table 6 Input data: Organic wheat flour

**Unit is per FU unless indicated specifically*
***Details are in Appendix I: Machinery activity*

4. Results

4.1. Global Warming Potential

The difference in the GWP between the organic and conventional systems is obvious in this study. The total GWP for the conventional systems is 356 kgCO_2eq/FU, and 249 kgCO_2eq/FU for the organic systems. As shown in Figure 6, farm activity from both systems is accounted for most of the emissions, while transportation and milling have the least contribution. In conventional farming, farm activity accounts for 96% of the total emission, and in organic farming, it is 95% of the total GWP. Transportation and milling activities account for 3.5% and <1% respectively in conventional farming. And in organic farming, transportation accounts for 4.7% and milling accounts for <1% (see Figure 6).

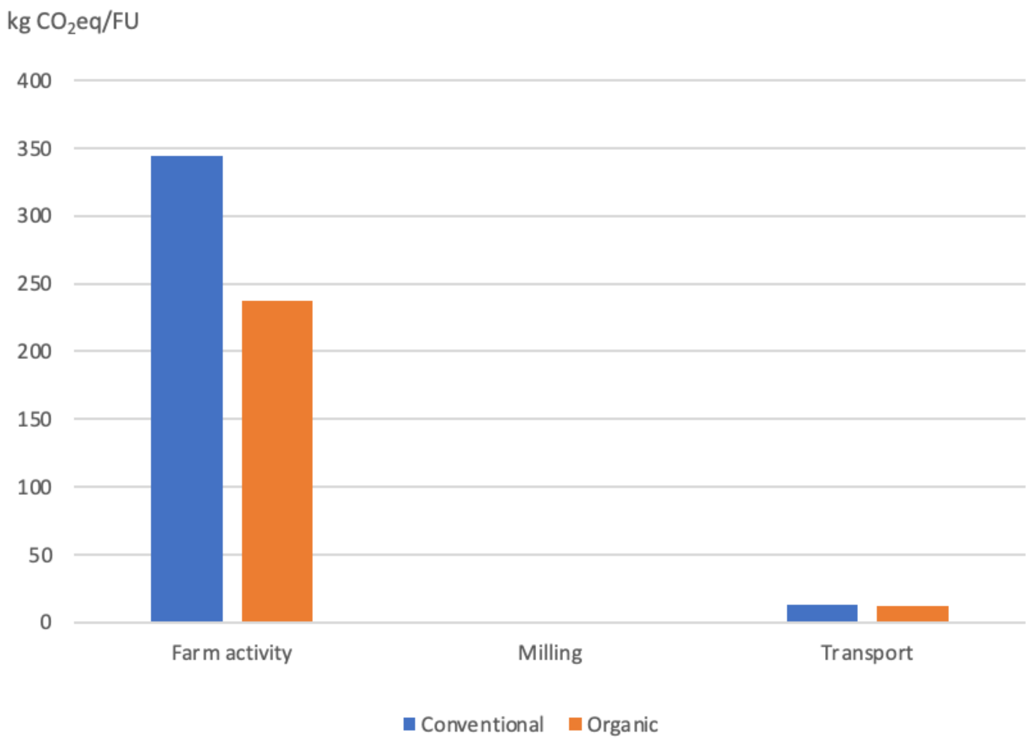

Figure 4 Contribution of different stages to GWP

Furthermore, as shown in Figure 7, the ammonia nitrate contributes 83% of the total emission of farm activity in conventional farming followed by wheat seed and pesticides use.

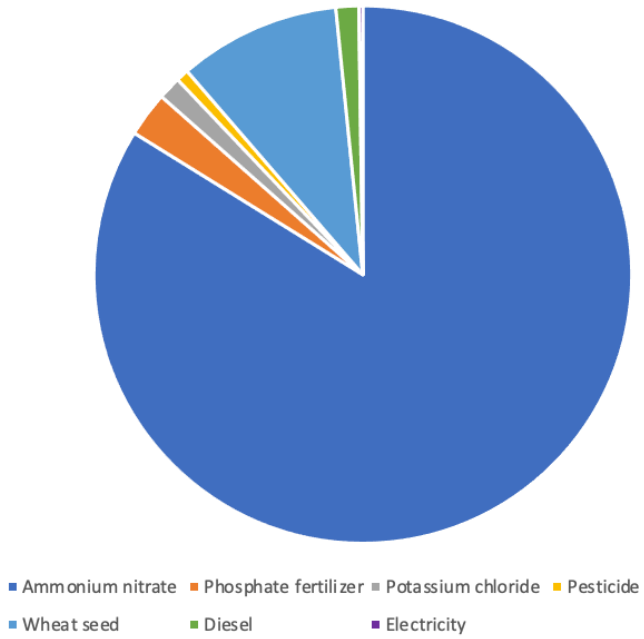

Figure 5 The percentage of GWP from each farm activities in conventional farming

In the organic systems, green manure accounts for most of the emissions which is 81% of the total farm activity emission (see Figure 8). Wheat seed and diesel use in the second and third contributors in organic farming.

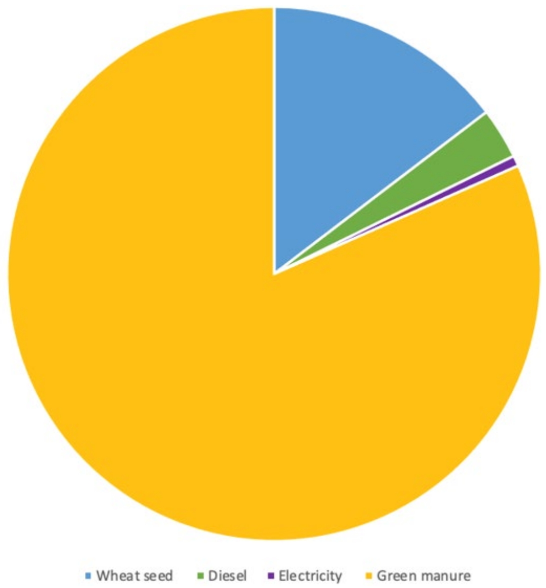

Figure 6 The percentage of GWP from each farm activities in organic farming

4.2. Energy Use

For energy use, the two systems have similar outcomes. For conventional farming, the energy use is 4025 MJ/FU, and for organic farming, its 3983 MJ/FU. Similar to the GWP, the farm activity in each system contributes more than 90% of the total energy use. The transportation (5%) is the second, and the milling (<1%) is the least (Figure 9).

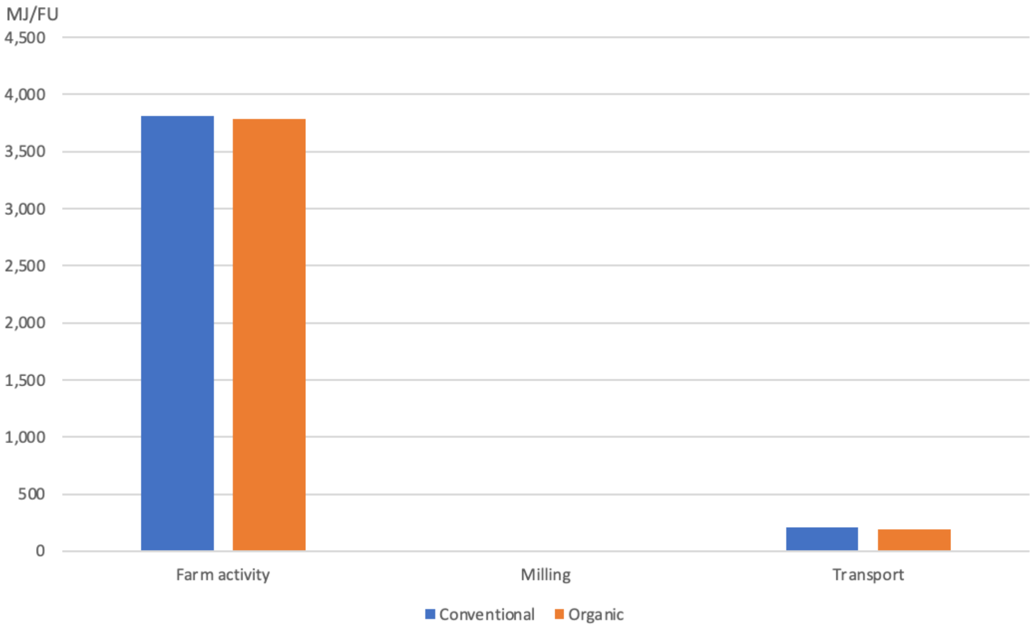

Figure 7 Energy demand of conventional and organic systems

As shown in Figure 10, ammonium nitrate has the highest energy use in the farm activity of conventional farming. The second one is wheat seed followed by diesel use.

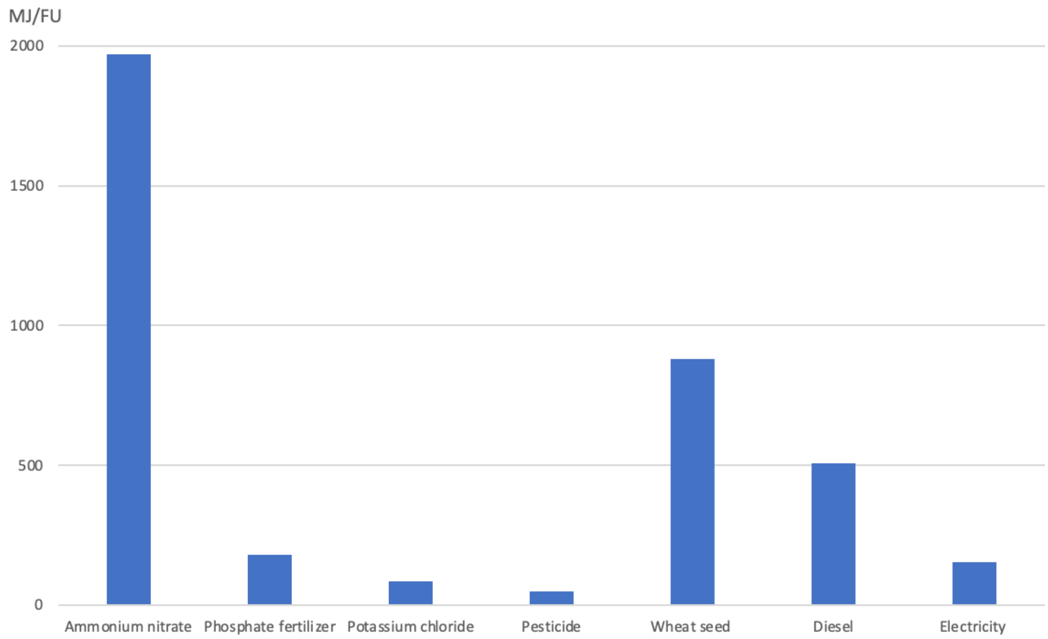

Figure 8 Energy use contribution of different activities in conventional farming

In terms of farm activity in organic farming, the organic wheat seed is contributing the most to the energy use, followed by diesel use and green manure (Figure 11).

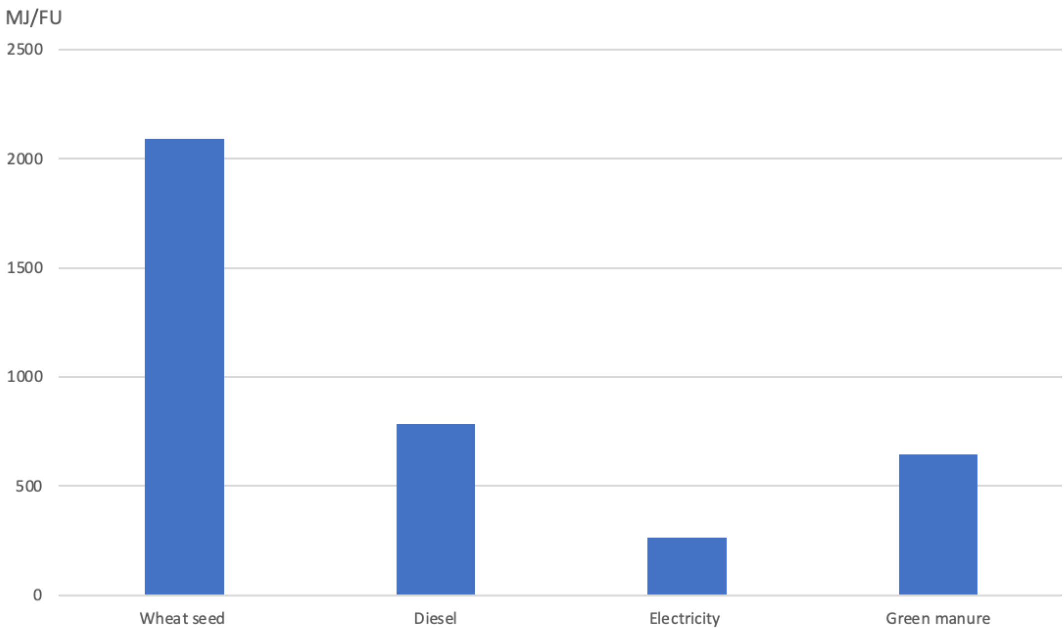

Figure 9 Energy use contribution of different activities in organic farming

5. Discussion

5.1. Global Warming Potential

In this study, the GWP of conventional wheat farming is 356 $kgCO_2eq/FU$, in which the farm activity contributes the most with 344 $kgCO_2eq/FU$. Among all the activities that happen in the farm stage, fertilizing with nitrogen has the highest contribution to the GWP. This result is in alignment with previous studies. Bernesson et al. (2006), Tidåker et al. (2007), Tuomisto et al. (2012b), Casolani et al. (2016), and Rajaniemi et al. (2011) all reported that the nitrogen fertilizer has a big contribution to the GWP. The two main reasons why synthetic nitrogen fertilizer has such a big impact on emission are manufacture and application (Hasler et al., 2015). The use of fossil fuel in ammonia production causes a large amount of GHG emissions (ibid). Meanwhile, Hasler et al. (2015) also concluded that using the right ingredients while producing nitrogen fertilizer can reduce the emission by up to 20%. For example, using calcium ammonium nitrate instead of urea. Furthermore, using a fertilizer with lower content of nitrogen can also help to reduce GWP substantially since the impact on climate change from N_2O is 298 times higher when comparing to CO_2 (ref.). Therefore, using improved fertilizers and a better way of applying them enables to decrease the environmental impact.

The present study found that GWP of organic farming is 249 $kgCO_2eq/FU$ which is significantly lower than conventional farming. The main reason is the absence of synthetic fertilizers and pesticides. Nevertheless, same as the conventional farming system, the farm activity in the organic system also contributes the most in GWP which is 237 $kgCO_2eq/FU$. And in the farm activity, the application of green manure has the highest contribution which is 193 $kgCO_2eq/FU$. This includes the emission from all the machine operations (including soil cultivation, sowing, and mulching), corresponding machine infrastructure, sheds, seeds, as well as the direct field emissions that happened during the cultivation of the legumes. Even though the GWP in the organic system is already lower than the conventional system, there is still a way of improving it. Knudsen et al. (2014) conducted a set of LCAs comparing the environmental impacts from different nitrogen sources and suggested that harvesting and fermenting the legumes to produce biogas (which can further replace fossil fuel) and applying the residues to the field can massively decrease the carbon footprint of organic farming (-65 kg CO_2 eq./t dry matter). However, the study from Knudsen et al. (2014) was based on assumption. There is still a lot to discover in the practice.

5.2. Energy Use

The energy use of the conventional wheat system in the current study is 4025 MJ/FU. Similar to the GWP, most of the energy demand happens in the farm stage, in which ammonia nitrate uses 1969MJ/FU, wheat seed uses 879MJ/FU, and machinery (diesel) uses 507 MJ/FU.

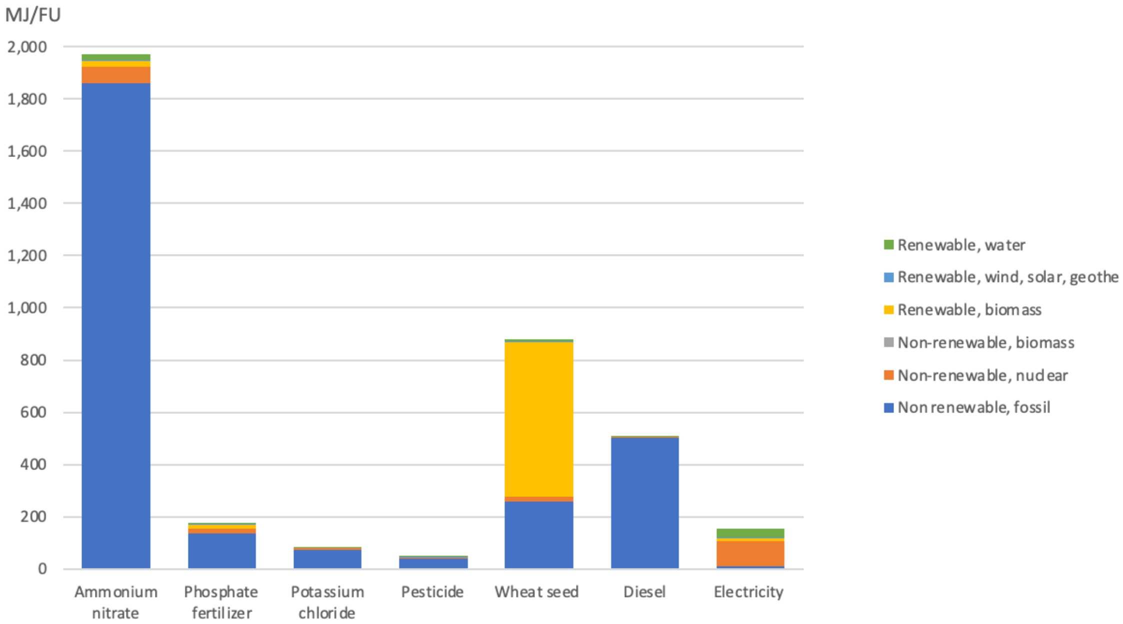

Figure 10 Energy source of different activities in conventional farming

As shown in figure 12, the main energy demand from ammonia nitrate is the use of fossil fuels. This is consistent with the conclusion from Hasler et al. (2015). There is a high demand for energy when producing ammonia nitrate. In database Ecoinvent 3, the inventory of ammonia nitrate includes the production from ammonia and nitric acid. The transport of the raw material to the fertilizer plant, as well as the transport of the final product to the storehouse and further to the individual shop are included. Therefore, the use of fossil fuel in ammonia nitrate is significantly high. Regarding the wheat seed, the inventory includes the process of pre-cleaning, cleaning, drying, chemical dressing, and packaging. The storage and transport are also included. In terms of the diesel used in machinery, all the necessary transportation is included, as well as the operation of the petrol station and the storage tanks.

The energy use in the organic system in the current study is 3785MJ/FU. It is unexpected that the energy use of wheat seed in organic farming reaches such a high amount (2090 MJ/FU). This can possibly be explained by the lower yields than organic wheat has compared to conventional wheat. However, although the wheat seed in organic farming requires a lot of energy, the main source of energy is biomass which is renewable energy (Figure 13). In terms of environmental impact, renewable energy is better than nonrenewable energy like fossil fuel. The diesel use in machinery (783 MJ/FU) and green manure (646MJ/FU) are also notably high. Even though there is less process in the organic system that requires diesel, the diesel use per FU is higher due to the lower yield. Therefore, the energy demand in the organic system is close to the conventional system regarding diesel use. In terms of green manure, the inventory includes all the machine operations in the field when cultivating the legumes for green manure use.

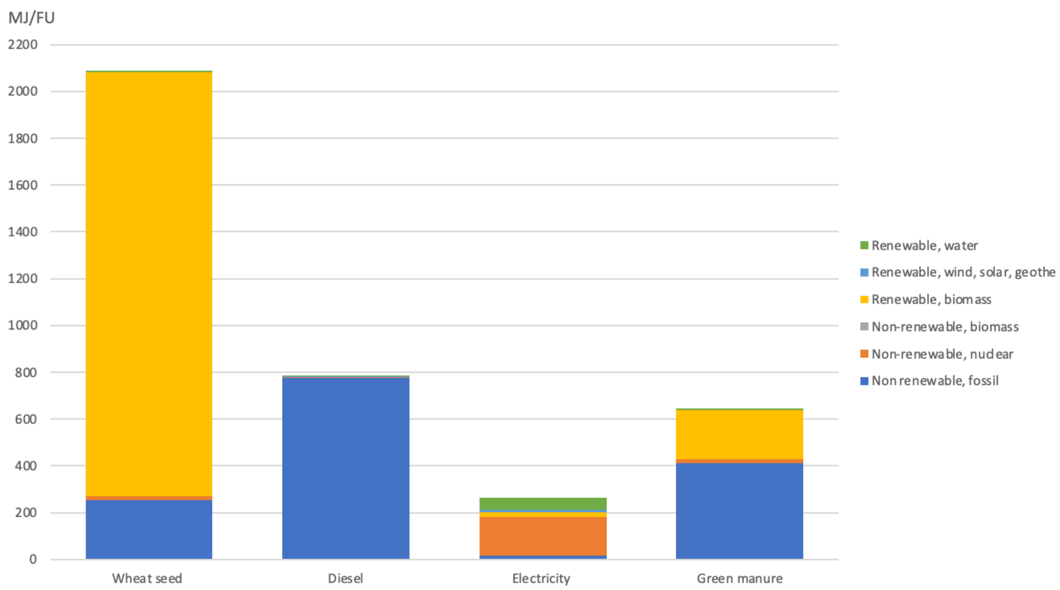

Figure 11 Energy source of different activities in organic farming

The author also used cow manure instead of green manure as fertilizer in the organic system. The energy demand is higher (4356 MJ/FU) compared to using green manure. This is due to the livestock management operation as well as the manure management. It is obvious that green manure has a better performance in terms of energy demand (Figure 14).

Add Figure 14 here

The reason that conventional and organic systems have similar energy use is that the organic wheat seed used in organic farming surprisingly requires a lot of energy.

One of the reasons is that the seed needs to be cultivated in an organic way which demands higher energy in the first place. The second reason is that organic wheat has lower yields therefore it needs more seeds to produce the same amount of wheat required by making 1-ton flour. However, most of the energy is renewable which is not the same in the conventional system. In the conventional system, the most energy-demanding component is ammonia nitrate which requires mainly fossil fuel.

In general, the energy use in the current study is higher than most of the literature. Ammonia nitrate in conventional farming alone contributes to 1969MJ/FU. This is because, in Ecoinvent 3, the inventory of ammonia nitrate includes not only the entire production of ammonia nitrate but also all the transport between fertilizer plant to the storehouse as well as to the market. In some studies (ref.), the transport and certain part of the production are normally omitted since they may have more accurate data from other sources. Another possibility is that some of the data is based on the average of global data therefore it may affect the accuracy to some extent. However, the results are still able to reflect some of the problems between conventional farming and organic farming in this study.

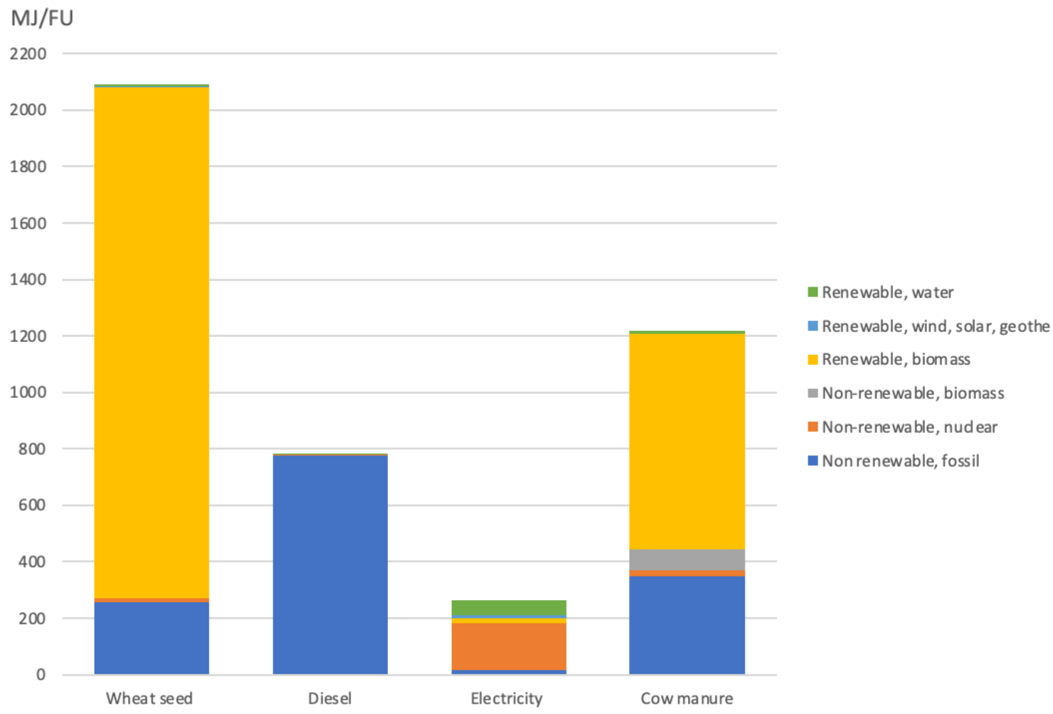

Figure 12 Energy source of different activities in organic farming (with cow manure)

5.3. Environmental Sustainability

In terms of GWP, the organic system is lower than the conventional system in the current study. However, the yield of organic wheat is significantly lower than conventional wheat. Because of the lower yield, the energy demand per kg of flour is almost the same in both systems. If organic wheat can have the same yield as conventional wheat, the GWP and energy demand will drop substantially (Figure 15 & 16). In this model, the author uses 6900kg/ha (high yield) as the yield of organic systems instead of the original yield which is 3990kg/ha (low yield). See the inventory table in Appendix 2. The reasons for organic wheat to have such a low yield are mainly because of the low soil nutrients as well as pests and weeds (Köpke et al., 2008). Therefore, the key challenge for the organic system is how to solve these problems.

Meanwhile, the key challenge for conventional farming is to have a better way of producing and applying fertilizers and pesticides. The high demand for fossil fuel energy when producing nitrogen fertilizer in conventional farming increases the total energy requirement considerably. It would be a good approach if fossil fuel energy can be replaced by other renewable energy so that the GHG emission can be reduced.

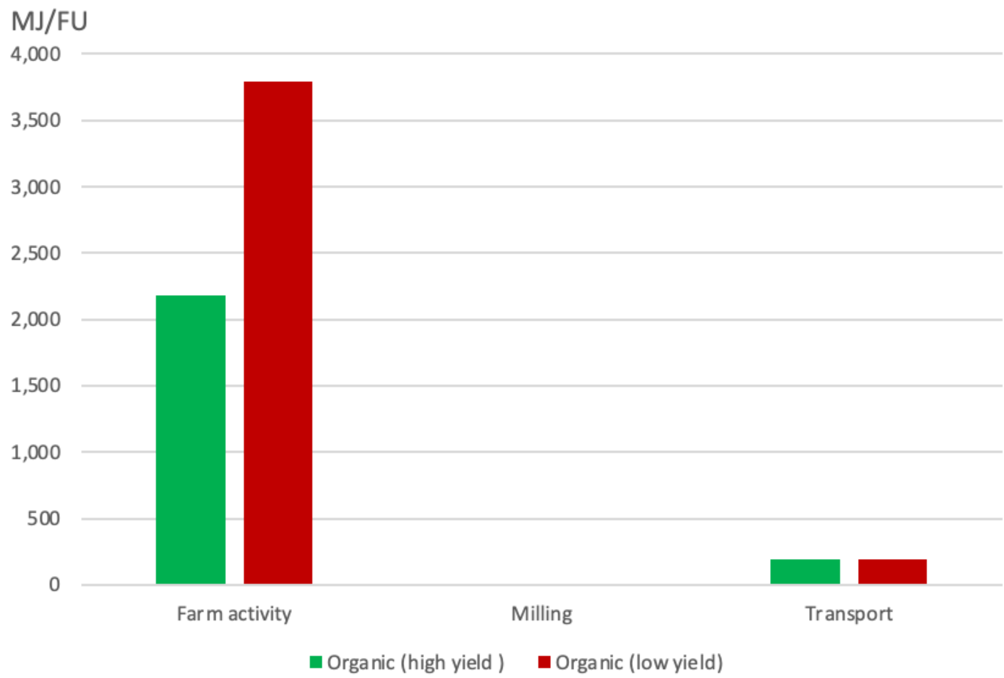

Figure 13 The difference of energy use with higher yield in organic farming

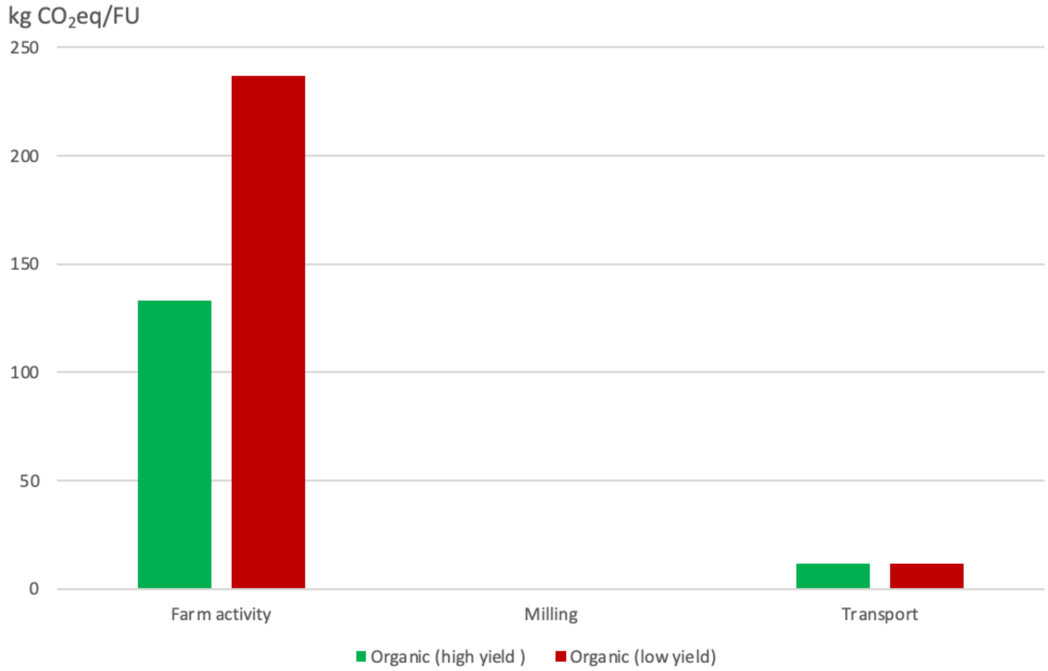

Figure 14 The difference of GWP with higher yield in organic farming

6. Conclusion

The main objective of the current study is to identify the environmental impacts of organic and conventional wheat flour produced and supplied in Sweden, using LCA to analyze the GWP and CED of the wheat supply chain. In terms of GHG emission, conventional systems have a higher emission compared to organic systems. As to energy demand, the two systems have almost equal CED values. The CED values for conventional and organic systems are 4025 MJ/FU and 3983MJ/FU respectively. The GWP values are 356 CO_2-eq kg/FU and 249 CO_2-eq kg/FU for the conventional system and organic systems respectively. Regarding GWP, the hot spot stage is the farm stage for both conventional and organic systems. The use of fertilizer and green manure has a massive impact on GHG emission. In the conventional system, the large GHG emission is due to the production and application of nitrogen fertilizer which can release a great amount of CO_2 emission. In the organic system, the emissions are caused during all the machine operation as well as direct emission from the field during the cultivation of the legumes, which contribute the main share of emissions from the farm stage. In terms of CED, the farm stage is still the hot spot stage. In the conventional system, the application of nitrogen fertilizer has the biggest demand for energy. The production of nitrogen fertilizer requires massive energy. In the organic system, the use of organic wheat seed has the highest demand for energy. This is due to higher input of the seed due to low yields in organic systems as well as the extra energy demand when producing the wheat seed organically. Even though the energy demand for organic and conventional systems is similar, the sources of energy are different. The energy source of organic wheat seed is mainly renewable energy while the energy source for producing nitrogen is mainly from fossil fuel. Therefore, if the source of energy is considered, the organic system has less environmental impact compared with the conventional system.

Overall, the most important hot spot is the use of synthetic nitrogen fertilizer. When solely considering the environmental aspects, organic wheat farming in Sweden is more sustainable than conventional wheat farming. However, increasing the yield for organic farming is crucial. The current study contributed a more recent and accurate data to the sustainability study of organic and conventional wheat cultivation in terms of GHG and energy use. Meanwhile, being sustainable does not mean only considering the environmental aspects.

Therefore, including social and economic aspects when doing further studies can be helpful to address the sustainability problem more effectively. Furthermore, including more indicator to evaluate the sustainability of wheat cultivation is also important. Like Korsaeth et al. (2014) and Alhajj Ali et al. (2016) stated in their study, soil emission and tillage system are also unneglectable contributor in terms of GHG emission and energy use. Therefore, it would be interesting factors to include in further studies.

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Ecoinvent 3., green manure, organic, GLO, ecoinvent database version 3.0.3.0

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Appendix 1

Detail on-farm activities and diesel use

Process	Machine	Unit*	Quantity	Comment
Tilling	Valtra 6600 Four-cylinder turbocharged engine Valmet (SISU) 420 DS at 75kW	L	1.65	8 L/ha
Ploughing	Valtra 6650 Four-cylinder turbocharged engine Valmet (SISU) 420 DS at 75kW	L	3.10	15 L/ha
Sowing	Case IH MX 270 Engine power of 240kW	L	1.65	8 L/ha
Application of fertilizer	Valtra 6600 Four-cylinder turbocharged engine Valmet (SISU) 420 DS at 75kW	L	0.83	4 L/ha
Application of pesticides	Valtra 6600 Four-cylinder turbocharged engine Valmet (SISU) 420 DS at 75kW	L	0.41	2 L/ha
Harvesting	Massey Ferguson 7254 18 foot cutting table, Engine from SISU diesel, 634 DSBIEL, of 162 kW	L	4.96	24 L/ha

*Unit is per FU unless indicated specifically

Appendix 2

Input data for organic farming with the yield 6900kg/ha

Process	Unit	Quantity	Comment
Yield	kg/ha	6900	Winter wheat: 6900 kg/ha
Wheat required for 1t flour	kg	1428	
Farm activity	ha	0.2	
Green manure			
Seed use	kg	37.25	180 kg/ha
Field diesel**	MJ	358	47 l/ha
Electricity for drying	MJ	57.36	300 MJ electricity/ha
Milling			
Electricity	Wh	0.08	
Diesel	J	11.4	
Transport			
Farm to mill	tkm	71.4	50km

Appendix 3

Popular Science Summary

This study intends to study the GHG emission and energy use in organic and conventional wheat cultivation in Sweden. The reason to do this study is because the author wants to discover the difference between organic and conventional wheat systems, and to see if organic wheat is more sustainable than conventional wheat in terms of GHG emission and energy use. The purpose of choosing GHG emission and energy use is because they are the two indicators that are most recognizable and have the most influence on the public. By doing this study, the authors hope to raise the awareness of the public to pay more attention to what they are consuming as well as to put pressure on policymaker to make better regulations in terms of environmental protection.

One of the results of the current study shows that the nitrogen fertilizers that are used in conventional wheat systems are the biggest contributor to both GHG emissions and energy use. This is because of the high amount of diesel fuel are used as energy when producing nitrogen fertilizer. Diesel can create a great amount of CO_2 emission when burning which can cause negative effects on the environment. Another result the study finds is that even though organic wheat has lower GHG emissions compared to conventional wheat, the energy use in the two systems is similar. This is due to the lower production that organic wheat has. Organic wheat can only produce roughly half the amount of conventional wheat can produce with the same land area. Therefore, when they use the same amount of energy, the energy use per unit is much higher for organic wheat. If organic wheat can improve its production rate, it can be more sustainable in terms of GHG emissions and energy use. For conventional wheat, having a better way of producing as well as better raw materials for fertilizer can improve the performance regarding GHG emissions and energy use.

In this study, only two environmental indicators are considered when doing the research. However, sustainability is a big concept including all kinds of different indicators from environmental, social, and economic aspects. Therefore, the author hopes that more research can be done to direct and engage the policymakers to formulate more complete regulations strategies for a more sustainable world.