Evaluation of biodiesel as heating fuel

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This is a limited LCA comparison of emissions from biodiesels and light fuel oil, when produced and combusted in an oil boiler. The biodiesels is made from different raw materials.

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2009-12-08

Abstract

The aim with this study is to investigate how large of an impact the biodiesel has on the environment compared to light fuel oil, when combusted in oil boiler. The research includes biodiesel from three different raw materials.

The biodiesel is produced at Tolefors gård, located in Östergötland around 10 km outside Linköping. The farm is owned and run by Axel Lagerfelt and his family. They produce around 170 000 liter biodiesel per year and sell everything to Linköpings kommun which uses it for heating up some schools around Linköping. Both they and Tolefors gård are interested in this study, made at Linköpings University.

The research is made by performing a Life cycle assessment (LCA) in the LCA software SimaPro. Because of the time and resource limitations most of the data collected are quantitative which is mostly taken from other reports. Some qualitative data comes from Axel Lagerfelt orally and via email.

The first biodiesel in this comparison is made from rapeseed oil produced at Tolefors. The rapeseed is grown at fields of the farm and is then dried and pressed in small scale production. The rapeseed oil is thereafter used for biodiesel production.

The second biodiesel is also made from rapeseed oil, imported from Belarus. The rapeseed is grown in Belarus and also dried and pressed there. The oil is then transported to Tolefors where the biodiesel is produced.

The last biodiesel compared in the study is made from fish waste oil from Norway. The fish waste is pressed and the produced oil is transported to Tolefors for biodiesel production.

In the comparison the emissions from the production and the combustion of the biodiesels and the light fuel oil are calculated together and compared. The emissions for the production of one mega joule of heat are calculated to be able to compare the different fuels.

When the rapeseed is pressed to oil a waste product is the seedcake. In fish oil production the waste product can be milled to meal. Both these waste products can be used for animal food. This fodder can replace soy meal that is often used for production of animal food. This avoided production of soy meal has been included in the calculations of the emissions from the biodiesel production. The biodiesel production will then replace a certain amount of soy meal production.

The results show that biodiesel is better than light fuel oil in regards to the environmental issues investigated in this study. The processes with the highest environmental impact for the biodiesels are the electricity, the fertilizers, the combustion, the transports and the diesel consumption of the tractors. The biodiesel based on fish oil is the best one from an environmental perspective, because it is made from a waste product and requires no fertilizers or tractor driving.

Sammanfattning

Syftet med denna studie är att undersöka hur stor påverkan biodiesel har på miljön i jämförelse med eldningsolja vid förbränning i oljepanna. Undersökningen inkluderar tre olika sorters biodiesel som är producerade från olika råmaterial.

Biodieseln produceras på Tolefors gård belägen i Östergötland någon mil utanför Linköping. Axel Lagerfelt med familj äger gården och producerar cirka 170 000 liter biodiesel om året. All biodiesel säljs till Linköping kommun för uppvärmning av skolor inom Linköpingsområdet. Både Linköpings kommun och Tolefors gård är intresserade av denna studie som är gjord på Linköpings Universitet.

Studien är gjord med hjälp av en Livscykelanalys (LCA) och dataprogrammet SimaPro som är ett dataprogram för genomförande av LCA. På grund av begränsningen i tid och resurser är det mesta av den insamlade data kvantitativ. Data är främst tagen ifrån redan tidigare utförda undersökningar men även från Axel Lagerfelt och andra referenser.

Den första biodieseln som jämförs är rapsoljebaserad biodiesel som görs på raps från Tolefors. Rapsen odlas på gårdens åkrar och torkas och pressas sedan för produktion av rapsolja. Rapsoljan är används för att producera biodiesel.

Den andra biodieseln är också rapsoljebaserad men rapsoljan importeras från Vitryssland. Rapsen odlas i Vitryssland där den även torkas och pressas. Den transporteras sedan som rapsolja till Tolefors där biodieselproduktionen sker.

Den sista biodieseln som jämförs i denna studie är baserad på fiskrester från Norge. Fiskresterna pressas och fiskolja produceras som sedan transporteras till Tolefors där biodieselproduktionen sker.

Jämförelsen görs mellan de tre biodieselsorterna och eldningsoljan genom att alla utsläpp som sker inom produktionen samt utsläppen vid eldningen räknas ihop och jämförs. För att kunna jämföra de olika bränslena beräknas alla utsläpp för att producera en megajoule värme.

När rapsolja tillverkas så återstår en frökaka som kan användas till djurfoder. Vid produktion av fiskolja återstår en restprodukt som kan malas till fiskmjöl som även detta kan användas till djurfoder. Fodret kan ersätta sojamjöl som ofta används i djurfodertillverkning. Detta tas med i beräkningarna för biodieseln som då ersätter produktionen av en viss mängd sojamjöl.

Resultatet visar på att biodiesel är bättre än eldningsolja med hänsyn till alla de olika miljöfaktorerna som beräknats i denna studie. De processerna som påverkar miljön mest i de olika biodieselsorterna är elektricitet, gödningsmedel, förbränningen, transporter och traktorernas dieselförbrukning. Biodieseln som baseras på fiskolja är den biodiesel som är bäst ur ett miljöperspektiv beroende på att den är baserad på en restprodukt. Den kräver dessutom ingen gödning eller diesel för traktorer.

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1. Introduction

At present one of the biggest challenges in the world is to rid the dependence of fossil fuels. Fossil fuels are without a doubt the most dominant energy sources in the world. They are used for heating, electricity production, transport fuels etc. There are two big issues with fossil fuels which always are in debates. For the first it is a limited source and will not last forever. The second big issue is of course the emissions from the fossil fuels where the most common debates is about the global warming caused by emissions of carbon dioxide. The oil crisis in the 70s had the effect that many countries tried to be more independent of oil. Thereafter, biofuel development started and is now a growing industry. A benefit for biofuels is that they are applicable on existing infrastructures around the world.

The growing production of biofuels has led to the well known debate; food vs. fuel. Different studies give different answers if it has to be a competition or not. A pro biofuel contribution in the food vs. fuel debate is the following. Nearly 38% of the corn produced in the USA is used for animal food and 30% is used for ethanol production [1]. For the ethanol production the starch in the plant is used and in biodiesel production, the starch (in form of alcohol) and the oil are used. The most interesting part of the plant for the animal food is the protein [2]. So after ethanol and biodiesel are produced, from in this case corn, the waste product can be used for animal food.

There is however one thing that everyone agrees about: the raw fossil oil is a limited resource and in the end new solutions are necessary.

1.1 Aim

Linköpings kommun and Tolefors gård are interested in quantifying how biodiesel, in comparison to using light fuel oil for heating schools, can improve their environmental performance.

The aim is to investigate how large of an impact the biodiesel has on the environment compared to light fuel oil. In the comparison biodiesel production from three different oils are included more exactly rapeseed oil imported from Belarus, rapeseed oil produced at Tolefors gård and fish oil produced in Norway. The main questions that are answered in the report are: Which of biodiesels has the least environmental impacts? Have the different biodiesels less environmental impacts than the light fuel oil? Where do the impacts come from?

2. Background

Biodiesel can be made from wide variety of different raw materials. Some of the oils commonly used include palm oil, corn oil and other vegetable oils. Apart from the vegetable oils biodiesel can also be produced from animal fat and fish oil. The most common raw materials in Sweden are rapeseed oil and waste oil from fast food production. [3]

2.1 Production of rapeseed oil

Before extracting oil from rapeseed, a pre-treatment to weaken the cell walls is made. That is done by milling the seeds mechanically. Then the actual extracting process starts. In the first steps over- and undersized particles are removed and after that the seed is preheated up to 30-40°C in order to improve the extractability. After cooking the flakes in 70-86°C, 60-70% of the oil is removed by pressing. In industrial production more oil can be extracted from the seeds and the pressed cake with hexane (the hexane is removed both from the cake and the oil afterwards). After the extraction the oil is purified. The purification includes for example neutralisation of free fatty acids and drying of water in the oil. If the oil is going to be used for food sometimes additives such as antioxidants are added. [4]

2.2 Production of fish oil

An example how to produce fish oil is to start with boiling the raw material (fish waste and or fish) in its own juice. Then the liquid part is separated from the rest by pressing. The dry mass can be used for producing fish meal. The liquid part goes in to a centrifuge where the oil is separated from the water. [5]

2.3 Biodiesel production process

The method used to produce biodiesel can vary depending upon the oil or fat used and the conditions presented. To obtain the most biodiesel out of the production a catalyst is used. The catalyst is oftentimes a strong base for example potassium hydroxide, sodium hydroxide or sodium methoxide. The biodiesel is produced in a process called transesterification where the oil reacts with methanol with influence of the catalyst.To get a good reaction, the transesterification is done at a temperature of around 70°C. It is also possible that instead of an alkali use other kinds of catalysts or skip the catalyst and use the alcohol in its supercritical state. [6]

The by-product from biodiesel production is glycerol. Earlier that was an expensive product and therefore was really good to sell to, e.g. the chemical market for production of cosmetics. Nowadays, however because of the shear explosion of glycerol on the market, the price is much lower. [2]

2.4 Tolefors gård

Tolefors gård is a farm located 10 kilometers west from Linköping city in Sweden. At Tolefors the Lagerfelt family is running a small scale production of biodiesel. The raw materials have so far been rapeseed oil produced at Tolefors gård, rapeseed oil imported from Belarus and waste oil from different restaurants. The current production is 170 000 liter diesel per year and all the diesel is sold to Linköpings kommun and used as heating diesel in a couple of schools around the city.

3. Method and references

The comparison between the biodiesel and the light fuel oil were done by performing a limited Life Cycle Assessment (LCA). The reason that the LCA only is limited is because of the limitation of both time and resources.

The first thing to do when performing a LCA is the *Goal and Scope definition*. This means that a functional unit is described and the system boundaries are made. The functional unit can e.g. be the production of one liter of diesel. The system boundaries tell what processes and flows that will be included in the LCA.

Secondly an *Inventory Analysis* is produced which comprises the data collection. This research is based mainly of quantitative data, but some qualitative data is also used.

The third thing is the *Life Cycle Impacts Assessment* which is the part of a LCA that relates an environmental impact to an impact category. An impact category can for example be global warming, ozone layer depletion or eutrophication.

The final step is the *Interpretation* which means analysing the results. One part of the analysis is the sensitivity analysis which tests how sensitive the results are for changes of different inputs and emissions. [7]

3.1 Qualitative data

The diesel production at Tolefors gård includes qualitative data about the inputs of oil, sodium hydroxide and methanol and also the outputs. The electricity input is though quantitative data. All the qualitative data comes orally or via email from Axel Lagerfelt, the owner of Tolefors gård.

3.2 Quantitative data

The quantitative data was found in different ways on the internet. Information was both found in scientific articles that are published in data bases and on web pages that were estimated to be trustworthy.

3.2.1 Data research

Scopus and ScienceDirect are two different data bases with scientific articles that are available through the computers at Linköpings Universitet. They were used for the searching of general cases and already made LCAs about rapeseed- and rapeseed oil production in Sweden and Belarus and fish oil production in Norway. Examples of words and combination of words that were used in the searching are: rapeseed oil production, rapeseed production LCA, rapeseed production Belarus, rapeseed production Europe LCA, fish oil LCA, fish oil production, fish oil production Norway and fish oil production Europe. In both the data bases it is possible to search within the search results and some combinations were used in that way; rapeseed oil production + LCA as an example.

Some of the quantitative data were taken from research published on web-pages which were found via the web search engines google.com, google.se and google.no. For the quantitative LCA data the same combination of words, as the search in the data bases, were used at google.com. At google.se the combinations were translated into Swedish. Google.no was used for searching after information about fish production with the words “fish oil production LCA” translated into Norwegian.

3.3 SimaPro 7.1

SimaPro is a LCA software which was used for calculation of the impacts and the Life Cycle Impact Assessment. SimaPro also includes a database with data suitable for LCAs and some of the quantitative data was taken from there. As much as possible the data was taken from the EcoInvent library in the database. The method used for the LCA was the EPD 2007. EPD is a method that is recommended by the Swedish environmental management council [8]. The result is presented in six impact categories; *Global warming (GWP100)*, *Ozone layer depletion (ODP)*, *Photochemical oxidation* (Tropospheric ozone), *Acidification*, *Eutrophication* and *Non renewable, fossil* (the consumption of fossil fuels).

The program was one of the main problems that occurred. The processes and all the inputs, outputs and emissions that inserts to SimaPro need to have the correct units connected to each other. Also handling the software was an issue.

4. Goal and Scope definition

4.1 Problem definition

There are four different scenarios in this LCA which have a main function of heating up schools and no secondary functions. The scenarios are presented in Table 1.

Table 1: The goal/problem definition.

Scenario	Main function	Product	Functional unit	Reference flow	Key parameters
1	Heat up	Biodiesel made from rapeseed oil from Tolefors	Biodiesel with energy content of 1MJ	0.029 liter Biodiesel per functional unit	Rapeseed growing, Oil production, Biodiesel production
2	Heat up	Biodiesel made from rapeseed oil from Belarus	Biodiesel with energy content of 1MJ	0.029 liter Biodiesel per functional unit	Rapeseed growing, Oil production, Transportation, Biodiesel production
3	Heat up	Biodiesel made from fish oil from Norway	Biodiesel with energy content of 1MJ	0.029 liter Biodiesel per functional unit	Oil production, Transportation, Biodiesel production
3	Heat up	Light fuel oil	Light fuel oil with energy content of 1MJ	0.023 kg light fuel oil per functional unit	Oil extraction, Refining, Transportations

4.2 System boundaries

There are different main unit processes in the four different scenarios and these includes different elementary flows. Not included in the pictures (Figures 1-5) are unit processes that are not directly connected to the main flow. Since the data for the transportations are directly taken from the database of SimaPro, the emissions from the transportations are excluded in the pictures.

There is no picture on the scenario with light fuel oil since that whole process is taken from the SimaPro.

4.2.1 Rapeseed oil, Tolefors

All the processes in the "rapeseed from Tolefors" scenario are located at Tolefors gård, therefore no transports are needed. The rapeseed is growing on the farm fields and requires fertilizer, rapeseed, diesel for the tractors and biodiesel for drying the seed. In the oil production electricity is needed and in the biodiesel production methanol, catalyst and electricity is used. More details about the processes are to be read in the section 5.1.

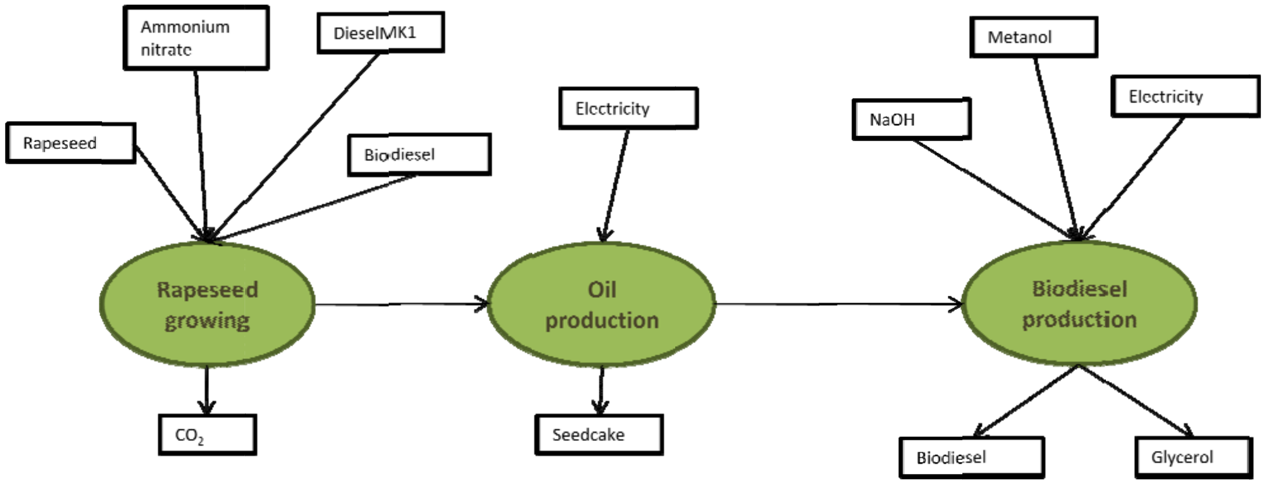

Fig. 1: The main unit processes in the Tolefors scenario.

4.2.2Rapeseed oil, Belarus

The only things that differ in Belarus compared to Tolefors are the light fuel oil for drying the seeds and the transport. The rapeseed oil is transported both with ferry. The light fuel oil is used instead of biodiesel. More details about the processes are to be read in section 5.2

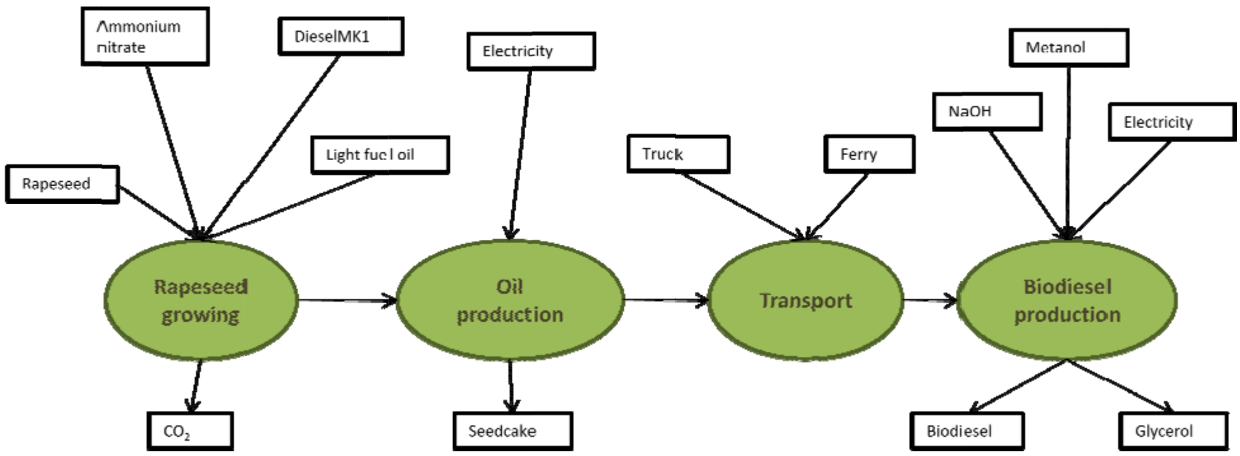

Fig. 2: The main unit processes in the Belarus scenario.

4.2.3 Fish oil, Norway

Because of the raw material in this scenario is a waste product, the flow starts with the oil production. The fish oil is transported with truck from Norway. More details about the processes are to be read in the section 5.3.

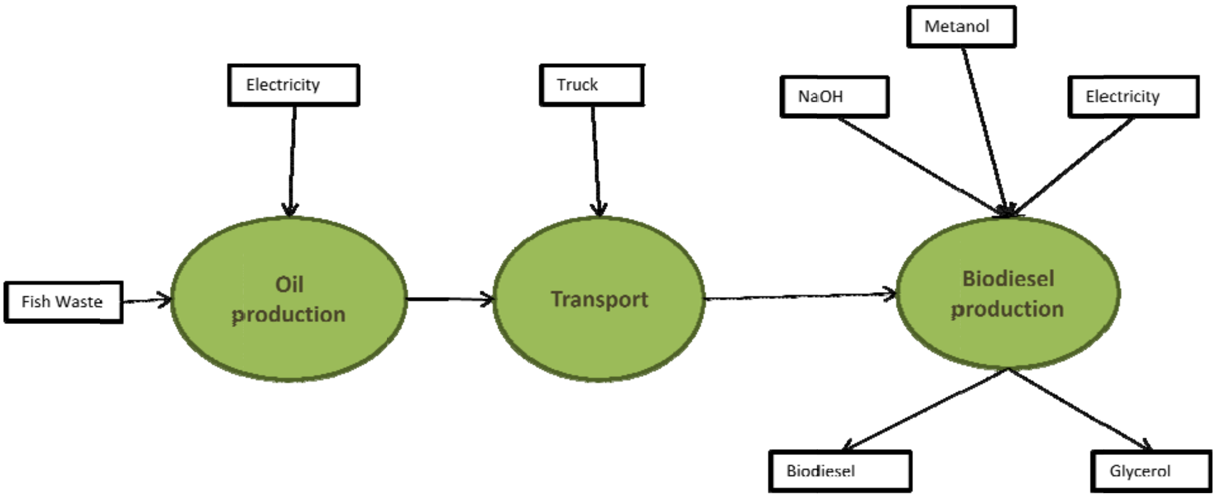

Fig. 3: The main unit processes in the fish oil scenario.

4.2.4 Combustion

For the combustion, an oil boiler and electricity are needed. The input is biodiesel and light fuel oil and the output are heat and some emissions to the air. More details about the combustion is to be read in section 5.6

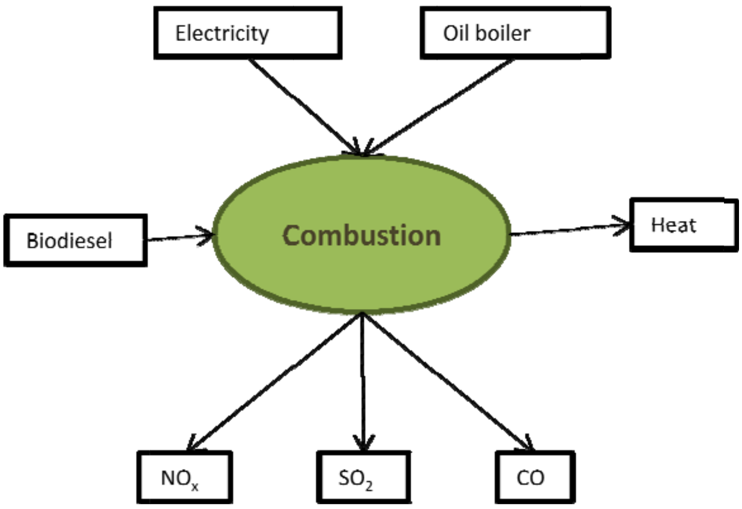

Fig. 4: Input and emissions when the biodiesel is combusted in an oil boiler.

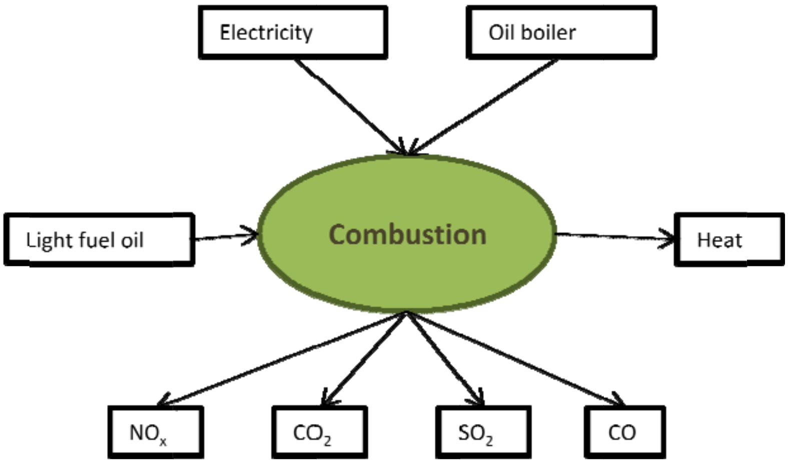

Fig. 5: Input and emissions when the light fuel oil is combusted in an oil boiler.

5. Life Cycle Inventory (LCI)

The LCA is made for compare the four different scenarios when biodiesel and light fuel oil are burned in an oil boiler. To be able to compare the fuels, the output in the simulation is one mega joule heat. Because of different energy content, different amount of biodiesel and light fuel oil is used. The same thing when making the biodiesel, different amount of raw material is used. All these data and flows are presented in Appendix B.

5.1 Rapeseed oil from Tolefors gård

From the beginning Axel Lagerfelt at Tolefors gård used his own produced rapeseed to produce biodiesel. That worked out, but the problem came when the rapeseed price went up and he got a better profit to sell the rapeseed than to make biodiesel of it. Now he uses imported oil or waste oil to produce biodiesel.

Because of the time limitation in this project an article about a LCA of rapeseed methyl ester production under Swedish conditions has been used as a main reference for this part of the project. The article is called "A limited LCA comparing large-and small-scale production of rape methyl ester (RME) under Swedish conditions" and is written by Sven Bernesson, Daniel Nilsson and Per-Anders Hansson. [9]

5.1.1 Rapeseed growing

In the article the location of the growing is in the flatlands of Svealand in Central Sweden but Tolefors gård is located in Götaland. The assumption is made that the growing conditions does not vary between the two areas. The article considers small (40ha), medium (1000ha) and large scale (50 000ha) production. Tolefors gård has a rapeseed production area of 110ha and can be assumed to be a small scale production. [9]

Rapeseed from previous year is used for sowing the fields, 8 kg per hectare are necessary. The emissions of CO_2 caused by light fuel oil during the growing procedure are assumed to be 73g/MJ_{fuel}. The consumption is 65.9 liters MK1 diesel oil per hectare. [9]For the growing procedure the fertilizer Axan with an ammonium nitrate content of 27 % is used. For one year of production, 130kg fertilizer per ha are used which is 0.0527 kg fertilizer per kg seeds (see Appendix A for calculation). [2] Since the content of the other substances in Axan are a so much smaller amount than the ammonium nitrate, they are neglected [10]. An ammonium nitrate fertilizer from the database of SimaPro is used in the LCI.

At harvest of rapeseed it is possible to get 2670 kg seed per hectare and it contains 15% of water which are then dried to contain 8% of water. The drying process uses 0,01liter of biodiesel per kg produced rapeseed (se Appendix for calculations). [2, 9]

5.1.2 Rapeseed oil production

After the drying process the seed contain 45% of oil and in small scale production the oil extraction efficiency is 68%. The electricity needed for the oil extraction is assumed to be 0.36MJ/kg seed in a small scale production. [9] The rapeseed cake is a by-product in the oil extraction and it is used as animal food.

At Tolefors gård, no hexane is used to get out more oil from the rapeseed cake because of small scale production. No transport is needed because the extraction and also later the biodiesel production is taking place at the farm.

5.2 Rapeseed oil from Belarus

When the rapeseed prices in Sweden went up it became better for Axel Lagerfelt in an economical way to sell the rapeseed directly instead of making biodiesel. But he still wanted to make biodiesel so he decided to buy rapeseed oil from Belarus and use this for produce the biodiesel.

5.2.1 Rapeseed growing

Information about rapeseed growing in Belarus appeared to be complicated to find with the resources available. Because of that, an assumption is made that the Swedish growing and the growing in Belarus is the same. The same inputs and outputs which are described in "rapeseed growing" under Sweden are used. The only different is that instead of the biodiesel, which is used at Tolefors for drying the seed, it is assumed that a light fuel oil is used in Belarus.

5.2.2 Rapeseed oil production

Also the oil production in Belarus was hard to find information about therefore the same assumption is made here as at "rapeseed growing".

5.2.3 Transport

A big issue with importing rapeseed oil from Belarus is the transport cost both economical and environmental. The rapeseed oil is assumed to be bought and produced in Minsk, the capital of Belarus, and then transported with truck to Linköping via Germany. That is the most economical way and it is calculated by the route planer ViaMichelin [11]. The distance is calculated to be 1818km with truck and 50 km with ferries between Germany and Denmark and between Denmark and Sweden. The truck from Belarus is assumed not to be so good because of the country's economical situation. Therefore it is calculated with a truck with class Euro 3 that was the worst class in SimaPro. The information from SimaPro about the truck and the ferries includes the details about inputs, outputs and emissions related to the production and the transportation.

5.3 Fish oil from Norway

Norwegian fish oil has not yet been used as a raw product for biodiesel production at Tolefors gård. But since it is a possible future suggestion it has been included in the research. There is fish oil produced from both the whole fish and from fish waste. The oil is assumed to come only from fish waste.

5.3.1 Fish oil production

It is assumed that the only inputs to the oil production are fish waste and electricity. This means that all possible cleaning of the oil are neglected. The electricity use in the fish oil production which are taken from a LCA made about Danish fish oil production. In that LCA, the electricity use for production of both fish oil and fish meal is calculated together. The total electricity use for production of 1 kg of fishmeal and 0.21 kg of fish oil is 0.19 kWh. The electricity use for only the oil production is assumed to be weight percentage of the whole electricity consumption, which is 0.16 kWh per kg of oil produced (see Appendix A for calculation). [5]

5.3.2 Transport

Since no fish oil has been imported to Tolefors gård yet the production location is presumed. The location is determined to be the region with the largest fishing quantity in Norway [12]. As an exact location Molde, the capital of the region, is used when calculating the transportation emissions. The distance is calculated to 908km by the ViaMichelin [11]. This truck is also taken from the database in SimaPro. It is assumed to be class Euro 4, which is one class better than the truck assumed in the Belarus case. That is because Norway is a richer country than Belarus.

5.4 Biodiesel production

Tolefors gård uses a small scale biodiesel processor from Ageratec for there biodiesel production. According to Ageratec the electricity consumption is 55-65W per liter produced biodiesel. That is 0.78 kWh per produced liter with the process time 12h and the electricity consumption 65W as a worst case (see Appendix A for calculation). [13] The other inputs are 0.92 kg of oil, 0.16 kg of methanol and 0.03 kg of NaOH for the production of one liter biodiesel. Except from the output of biodiesel there is an output of 0.2 liter of glycerol. [2] The glycerol is considered as a by-product and not included in the impact assessment.

5.5 Light fuel oil

The program SimaPro has in the database different kinds of oils and a "light fuel oil in Europe" is used. The oil in the program includes all the emissions values which are needed for example emissions from the transport, electricity and refining.

5.6 Combustion

The effect of the oil boilers at the schools that use the biodiesel from Tolefors gård is in the order of magnitude 100kW [14]. Therefore a process of burning light fuel oil in an oil boiler with the effect of 100kW is used for the combustion of the light fuel oil. The process is taken from the database in SimaPro and includes input of oil and the oil boiler and different emissions. In this calculation, only the largest emissions that also have the most consequences on the result, is included.

For the combustion of the biodiesel the emissions is different than for the light fuel oil. The emissions of CO are 90% lower than for the light fuel oil. The emissions of NO_x are 2.5% higher and the emissions of SO_2 are 16% higher (values are to be read in Appendix B). [15] The biodiesel is assumed to be carbon dioxide neutral. This means that the plant is bonding the same amount of carbon dioxide that is emitted *to* the air when the biodiesel is combusted. A new plant that replaces the old will then absorb the same amount *from* the air.

5.7 Electricity

The electricity in all different cases is the marginal electricity of Europe and currently it is coal. The marginal electricity in Europe is used because of the deregulated electricity market, which means that it is possible to buy and sell electricity between countries. The marginal electricity is the electricity produced last in the electricity mix and it would never be produced if the electricity was not needed. It is almost always the most expensive option. This means that less electricity from coal power plants in Europe will be produced if Sweden uses less electricity.

5.8 Avoided products

5.8.1 Avoided production of soy meal

When the rapeseed oil is produced the oil is the main reason for the production. The seedcake is a waste product and would not be produced if the oil was not wanted. The seedcake is used in production of animal food instead of soy meal. Soy meal is therefore an avoided product. The amount of produced seedcake will be the same as the amount of soy meal that is not produced. The emissions from the production of that amount of soy meal will be negative emissions in the LCA.

Fish meal is also a waste product that is used for production of animal food [16]. With same reasoning as above, the production of fish meal when producing fish oil will make soy meal to an avoided product.

5.8.2 Avoided production of light fuel oil

When drying the seeds at Tolefors, biodiesel is used instead of light fuel oil which means that less light fuel has to be produced. The amount of light fuel oil that is replaced with biodiesel will therefore be an avoided product in the rapeseed growing.

6. Results

The results are divided into the six different impact categories. In Fig. 6 the different combustion fuels are compared in relation to each other in each impact category. This is done by setting the worst fuel to 100% (or the best material is set to - 100%) and then the figure tells how much better (or worse for the cases with -100%) the other fuels are in comparison. As an example the light fuel oil has a 100% effect on global warming. The impact from the biodiesel from Belarusian rapeseed oil is almost 90% less in comparison.

The reason that some of the fuels have negative results is that they replace fuels with higher environmental impacts. This will be explained further in the analysis and the discussion.

Note: In the figures produced below, fossil oil is will be used instead of light fuel oil.

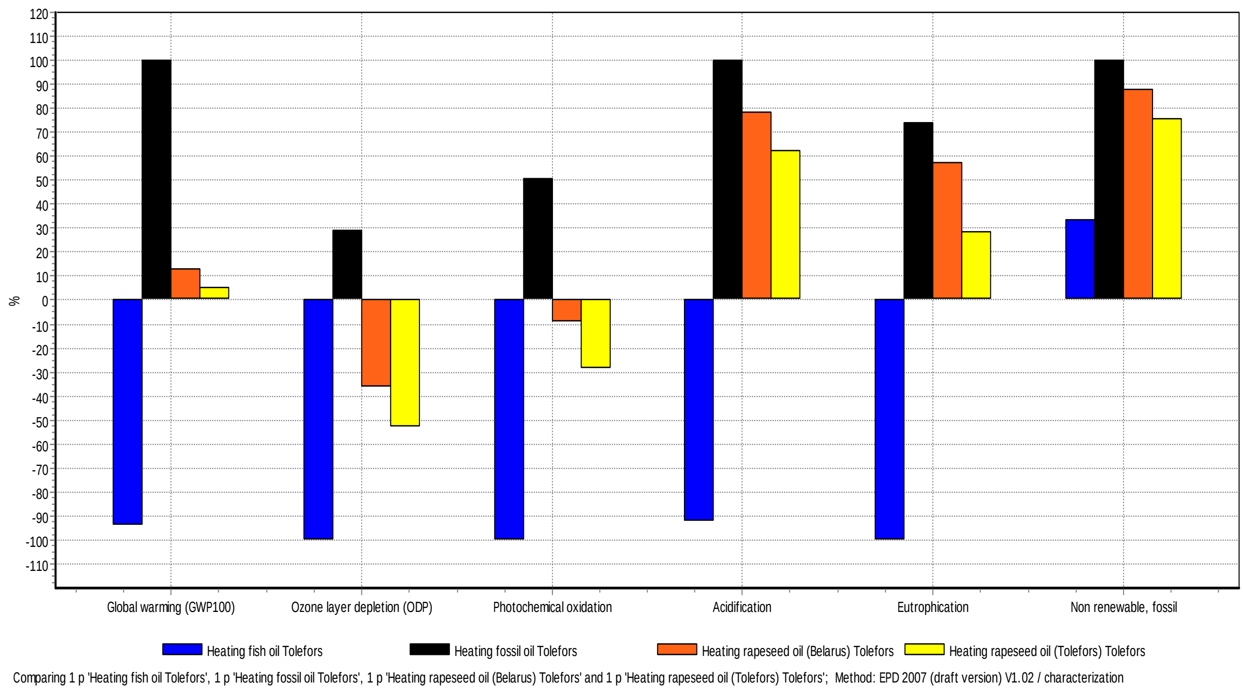

Fig. 6: LCA impact categories compared for the four scenarios

6.1 Impacts categories

Table 2 and Figures 7-12 shows the emissions for one year of production. In the impact category Global warming (GWP100), all of the emissions that contribute to global warming are recalculated to an equivalent of CO_2 that would be emitted. The same applies also for the other impact categories; the emissions are recalculated into one specific emission equivalent based on that which is most relevant for each impact category.

Table 2: Emissions from the four scenarios

Impact category	Unit	Fossil oil	Biodiesel Rapeseed oil, Tolefors	Biodiesel Rapeseed oil, Belarus	Biodiesel Fish oil, Norway
Global warming (GWP100)	kg CO2 eq	510 165,83	27 155,63	67 622,21	-478 919,77
Ozone layer depletion	kg CFC-11 eq	0,06	-0,11	-0,08	-0,21
Photochemical oxidation	kg C2H4	138,33	-76,93	-24,86	-271,28
Acidification	kg SO2 eq	1 311,54	816,10	1 030,58	-1 213,34
Eutrophication	kg PO4--- eq	104,65	40,66	81,24	-141,74
Non renewable, fossil	MJ eq	7 351 479,70	5 564 225,70	6 442 724,10	2 457 084,60

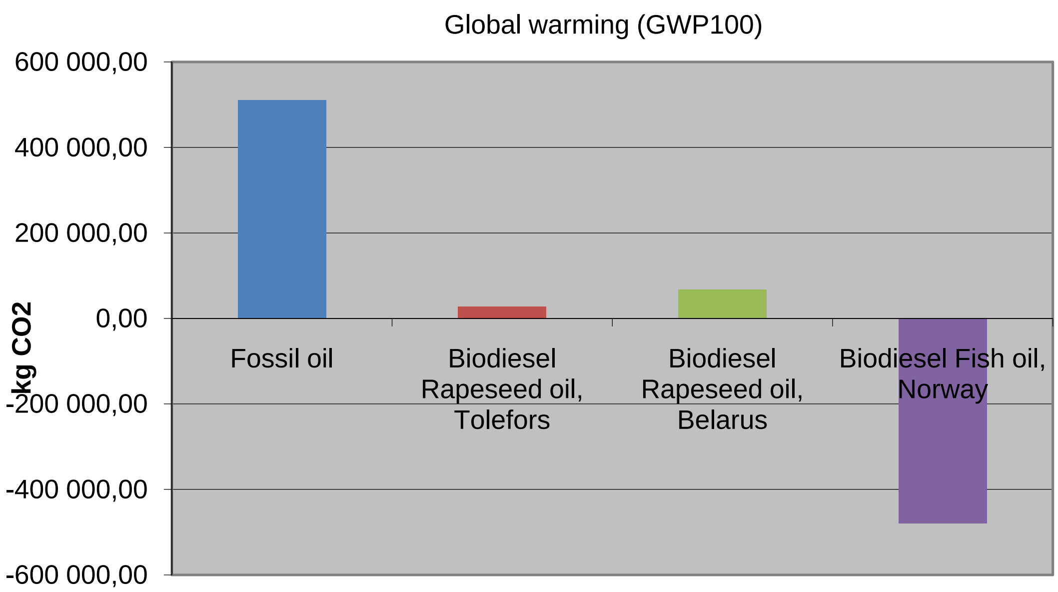

Fig. 7: Emissions that contribute to global warming.

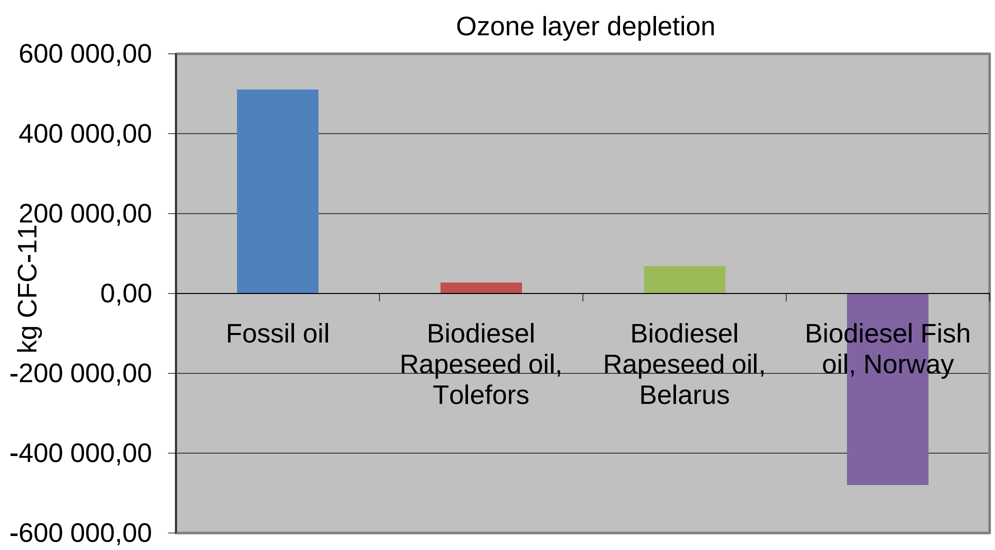

Fig. 8: Emissions that contribute to ozone layer depletion.

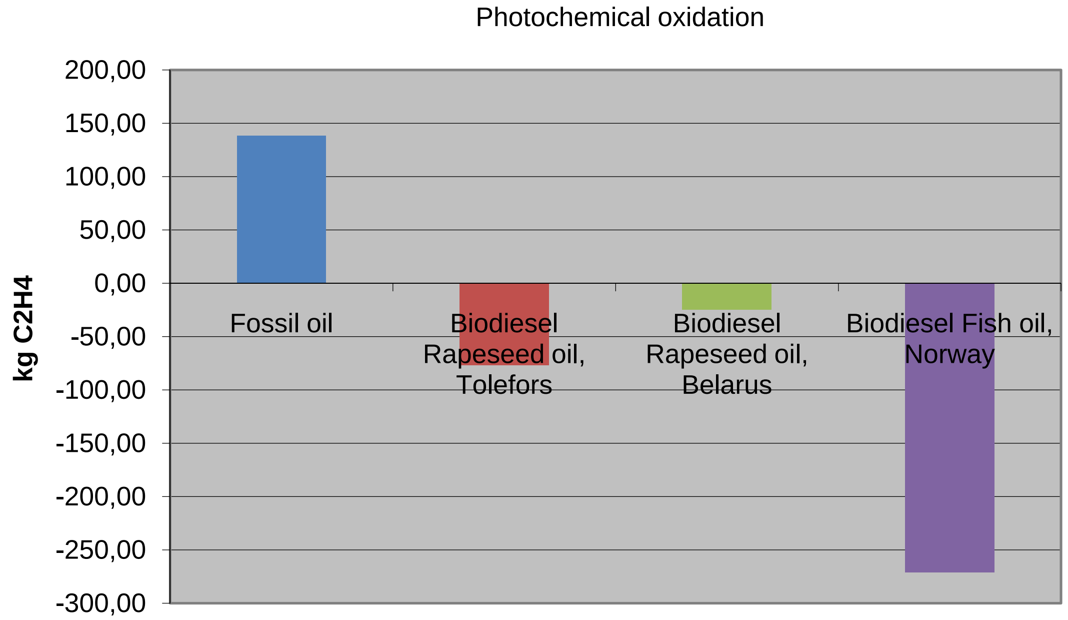

Fig. 9: Emissions that contribute to photochemical oxidation.

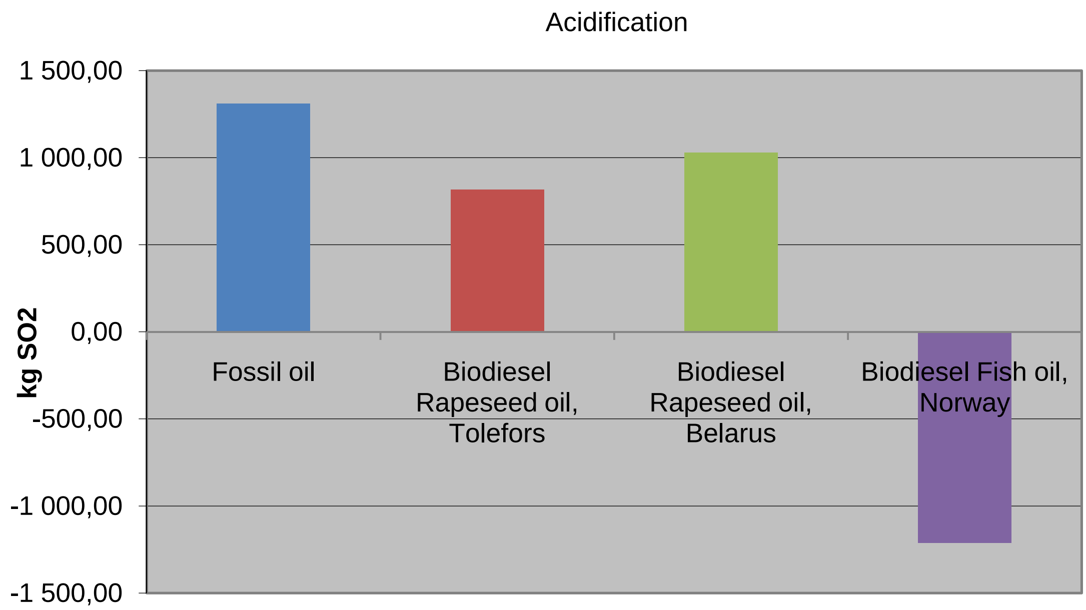

Fig. 10: Emissions that contribute to acidification.

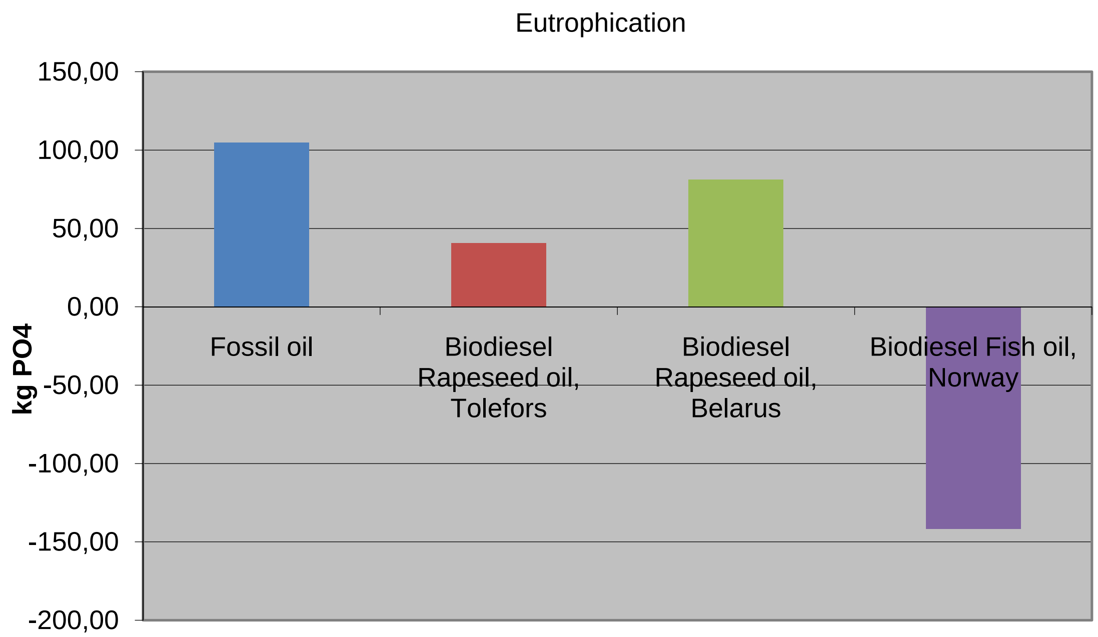

Fig. 11: Emissions that contribute to eutrophication.

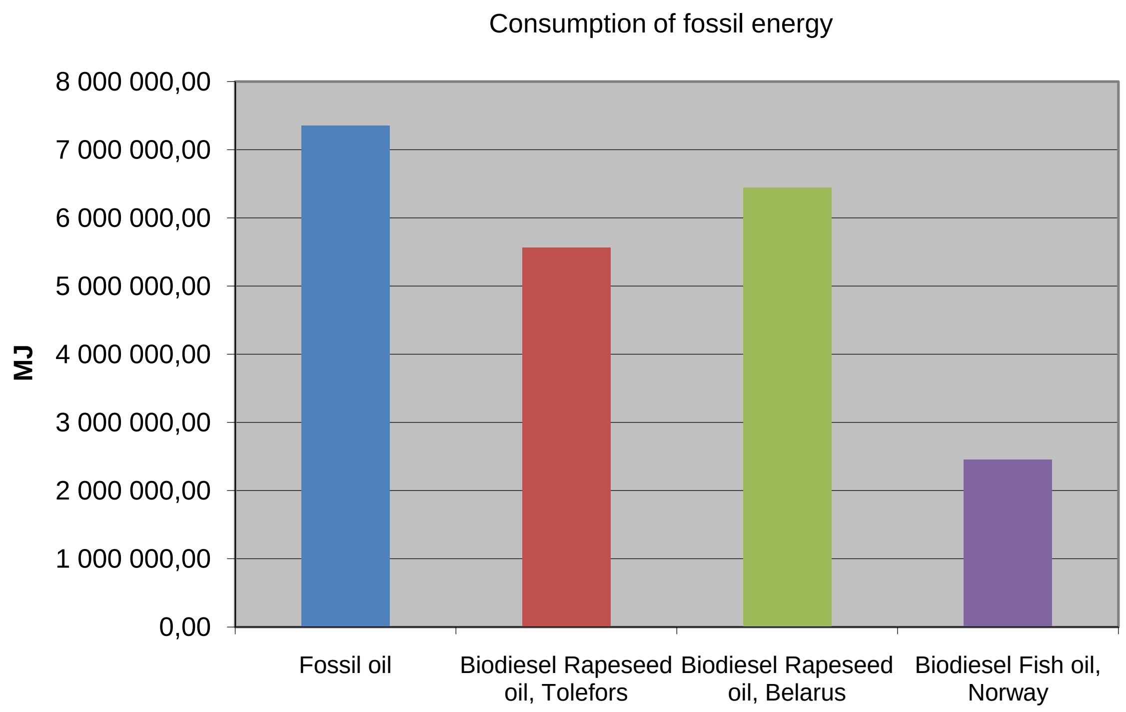

Fig. 12: Consumption of fossil energy.

7. Analysis

In each impact category the most significant reasons of the impacts are mentioned. A list of the five processes that have the largest impact on the impact category in each scenario is to be read in Appendix C.

7.1 Global warming

The light fuel oil has the most impact on the global warming. The most important processes for the global warming are the combustion and the refining of the light fuel oil and the electricity from coal power plants.

Biodiesel is assumed to be carbon dioxide neutral and has a low impact on the global warming. The largest processes for the rapeseed based biodiesel are electricity, fertilizer, rapeseed growing and for Belarusian rapeseed oil-based biodiesel, the transport to Sweden.

The biodiesel from fish oil has negative emissions of carbon dioxide. The processes with the highest impact on the global warming are the electricity, the methanol production and the transport to Sweden. All the biodiesel scenarios have negative impacts on the global warming because of the avoided product soy meal.

7.2 Ozone layer depletion

The emissions that affect the ozone layer look almost the same as for the global warming. The light fuel oil causes most problems and the emissions from the biodiesel made from fish oil are negative. It is the refining of the light fuel oil that causes the most emissions.

In the Tolefors gård and the Belarus cases are the processes with the highest ozone layer depletion emissions the tractor driving on the field, the methanol production, the fertilizer, the electricity and in the Belarus case the transport. As for the global warming the processes with the largest impact, for fish oil based biodiesel, are the methanol production, the transport to Sweden and the electricity.

The biodiesel emissions are low because of the avoided emissions, which depend on the transport of the soy meal.

7.3 Photochemical oxidation

For the photochemical oxidation all the scenarios with biodiesel have negative emissions. The largest emissions for the biodiesel are from the electricity, the combustion and the sodium hydroxide in the production of biodiesel. The emissions become negative because of the avoided transport of the soy meal.

The emissions from the light fuel oil come especially from the refinery, the combustion and the electricity.

7.4 Acidification

For the acidification, the light fuel oil and the biodiesel from rapeseed are all bad. The emissions come mainly from the combustion, the electricity from coal power plant and the fertilizer. The fish oil based biodiesel is better because no fertilizer and not so much electricity are used. The combustion of light fuel oil affects the acidification less than the combustion of biodiesel, but the transport of soy meal is avoided and therefore the emissions are lower for the biodiesel.

7.5 Eutrophication

The result of the eutrophication looks almost the same as the result of the acidification. The largest impacts from the rapeseed based biodiesel are the electricity, the fertilizer, the combustion and for the Belarus case, the transport. It is the same for the fish oil based biodiesel as for the Belarusian rapeseed oil-based biodiesel, except the fertilizer.

The highest impacts from the light fuel oil on the eutrophication come from the refining, the combustion and the electricity.

Also for the eutrophication, the avoided transport of the soy meal is a large negative emission in the biodiesel scenarios.

7.6 Non renewable, fossil

The result from the consumption of light fuel oil shows that the light fuel oil uses the majority of the fossil energy per MJ heat. The biodiesel scenarios use fossil energy in the coal power plants and in the methanol production. At the rapeseed field some diesel are used for the tractors and the fossil energy is used in the fertilizers transportation and production. The fish oil and Belarusian rapeseed oil are transported to Sweden which also uses a lot of fossil energy.

7.7 Sensitivity analysis

The sensitivity analysis is made in SimaPro. SimaPro uses the Monte Carlo simulation to see how much the probability is that one scenario is better than the other. All the three biodiesels are compared with the light fuel oil and the results are shown in Appendix D. E.g. the biodiesel from Tolefors (green bar) has lower impact on the acidification in 95% of the cases while the light fuel oil (red bar) has a lower impact with a probability of 5%.

8. Discussion

As the results appear, the biodiesel is always better than the light fuel oil regardless of raw material and impact category. The sensitivity analysis verifies that the result is stable against changes. For the biodiesels from different raw materials it is always best with fish oil followed by the rapeseed oil from Tolefors and thereafter the Belarusian rapeseed oil. This order is applicable in all the impact categories.

The biodiesel from the Belarusian rapeseed oil is, as said, the inferior biodiesel scenarios. It is interesting to see that it still has 87% less emissions, which impacts the global warming, than the light fuel oil. It also has 43% less emissions that impacts the ozone layer depletion and 85% less emissions that impacts the photochemical oxidation. In the impact category acidification, Belarusian rapeseed oil biodiesel is 21% better and in the impact category eutrophication it is 22% better.

The method EPD 2007 in SimaPro requires the six impact categories that are used in this LCA. This method shows a wide range of impacts in order to provide sufficient details about all processes and environmental impacts associated with them.

8.1 Growing conditions

In the rapeseed growing a lot of the quantitative data is taken from a report about rapeseed oil production in the Svealand region in Sweden. As Tolefors gård is located in the Götaland region it is not certain that the cultivation conditions are the same as in the report. If the conditions are better at Tolefors it would make the result a little bit better. If the conditions are worse it would make the result a little bit worse. The conjecture is though that the differences, if there is any, are small between the flatlands of Svealand and the flat land of Östergötland (where Tolefors gård is located).

8.2 Rapeseed drying with biodiesel

When the rapeseed at Tolefors is dried, biodiesel is used as energy source (which gives an avoided product). In the rapeseed production in Belarus it is assumed that the energy source is light fuel oil. If there is something else used for that process in Belarus, the result is in reality different. If biodiesel is used that gives a better result. If electricity is used that could change the result in both directions. Other fossil fuels, such as diesel and petrol, will probably not change the result so much. The same reasoning can be used about the avoided product in Tolefors. If there is electricity that is the avoided product, the result could be both better and worse and with another fossil fuel the result would probably be the similar.

8.3 The rapeseed oil production in Belarus

As mentioned earlier in the report, the effort to find information about rapeseed growing and rapeseed oil production in Belarus failed because of time and resource limitations. That made it necessary to assume that the rapeseed growing and the oil production is the same in Belarus as in Tolefors except for the drying process. The cultivation methods could be more/less efficient in Belarus than they are in Sweden which would make the result differ. But the oil production on the other hand is probably large scale and that could make it much more efficient. If the cultivation is less efficient, that means more arable land is needed for the same amount of seed produced. That would give a higher environmental impact because of more tractor driving etc. On the other hand less efficient cultivation means less fertilizer and less environmental impact in that regard.

8.4 Fish waste

The result of the biodiesel made from fish oil is very good. That is because it is assumed that the fish oil is made from fish waste. When the production starts with the waste are no environmental impacts from the fishing or the fish farming allocated the fish oil. This is a correct assumption if the fish is caught or produced for another reason e.g. for food. If the fish oil is made from fish, total or partly, it would be another situation which is impossible to speculate about, but clear is that the result would be worse. It is also to consider what would have happened with the fish if the oil and meal wasn't made. Would it been thrown away or would maybe biogas be produced? It is really hard to know how the result would differ if biogas was made, because then also the avoided fish meal production have to be considered. If it would be thrown away, the waste assumption is good. Something else that would change the result for the fish oil biodiesel, is if the fish meal is considered as the main product. If that is the case, the oil production wouldn't be included in the Life cycle inventory but on the other hand not the avoided soy meal either.

8.5 Transports

When the rapeseed oil is transported from Belarus and the fish oil is transported from Norway, a Euro3 respective a Euro4 truck is used. The Euro3 truck is chosen as worse case, since it is the worse truck in the SimaPro database. The Euro4 truck is chosen as an assumption that Norway, as a richer country, has better trucks. Euro4 is one class better than Euro3 and is also chosen as worse case (within the assumption of better trucks). If the transportations are performed with better or worse trucks, it would affect the result.

Molde in Norway is chosen as the place where the fish oil is produced. If the oil is produced somewhere closer or further away, the result would be better or worse.

8.6 Avoided soy meal production

In all the three scenarios with biodiesel, the soy meal is an avoided product. The soy meal doesn´t have to be produced if rapeseed meal and fish meal are produced as by-products and replace the soy meal. The fish meal can be used as animal food, but it is not clear from where the fish oil are going to be bought and therefore not possible to verify what happened with that fish meal. It can be used instead of soy meal but also instead of other meals or just thrown away. Even if it is just thrown away the fish oil based biodiesel are much better than the light fuel oil. The rapeseed cakes are, at least in Sweden, used as animal food and therefore the assumption that soy meal is replaced is good. It is uncertain what happens with the rapeseed meal in Belarus, but it would be an economical disadvantage to not use the rapeseed meal. The result would be affected if the soy meal is not avoided but it would probably not be worse than the light fuel oil.

8.7 Methanol

In the biodiesel production, methanol is used as an alcohol. Methanol is often a fossil alcohol and therefore it affects the results negative. With the second generation of biofuels, it is possible to make methanol from non fossil sources which would make the results better. This is not common right now, but will probably be in the future. It is also possible to make biodiesel with other alcohols e.g. ethanol which is not based on fossil oil. This would make the biodiesel a little bit more expensive but more environmentally friendly.

8.8 Glycerol

Glycerol is a by-product when producing biodiesel. Previously glycerol was a valuable product and assisted the biodiesel production economically. Nowadays the market price has crashed because of the increased production of biodiesel in the world. Glycerol is considered as a by-product in this LCA and therefore allocates no environmental impacts even if it is possible to sell it. If glycerol allocates some impacts, the results would be better for the three biodiesel scenarios compared with the light fuel oil. Glycerol could also be considered as a product that could avoid other production of glycerol, which would make the results even better for the biodiesel scenarios. This requires that it exists glycerol production where glycerol not is a by-product.

8.9 Electricity

The electricity is considered as marginal electricity which means that the most expensive electricity is on the marginal and are produced or not produced because of the demand. Because Sweden, Norway and Belarus are all a part of the European electricity market, the marginal electricity is used in all these countries. Currently the marginal electricity in Europe is produced in coal power plants. This affects the result and especially the use of fossil energy for all the scenarios. For the light fuel oil, the data are taken from the databases in the software SimaPro and therefore not all electricity is marginal electricity in that scenario. This affects the result for the light fuel oil to be better than the reality.

8.10 Are biofuels carbon dioxide free?

In this LCA, biodiesel is considered as carbon dioxide neutral, which means that the amount of carbon dioxide in the air is constant. A large discussion nowadays is about if biofuels really are carbon dioxide neutral. The argument for carbon dioxide neutrality is that the plant/organism is binding the same amount of carbon dioxide that comes out in the refining and the combustion. This requires that all raw materials are replaced with new plants/organisms otherwise biofuels can not be seen as carbon dioxide neutral. To produce biodiesel and combust it, is not totally carbon dioxide free because of the fossil energy used for tractors, electricity and so on. This has been considered in this LCA.

9. Conclusions

With the resources and the time available in this study, the main conclusion is that biodiesel is better than light fuel oil from an environmental perspective. The three different biodiesels have all less emissions than the light fuel oil, in all six impact categories included. Without doubt the best biodiesel is the one made from fish oil.

To improve biodiesel as a fuel even further, it is a good idea to look which processes that have the highest impacts in each category. In an overall view there are five processes that contribute the most to the impacts in more than one impact category. Those five are the electricity, the fertilizers, the transports, the combustion and the diesel consumption for the tractors in the rapeseed growing.

When evaluating the avoided products (the rapeseed cake that replace the soy meal as animal food and the biodiesel that replace the light fuel oil as drying fuel) there is more than simply the improved results and reduced emissions to take in account. If the products that replace the avoided once are used in the nearby area, they will be local products that replace internationally imported products. Using local products help to improve the local economy.

To find information about the rapeseed growing and the rapeseed oil production in Belarus was not possible with the limitations of the study. Because of that an assumption is made that the conditions were, with two exceptions, the same as in Tolefors. With the correct information about Belarus, the result would probably be different.

The electricity used in the biodiesel productions in this study is “worst case” electricity. There are different opinions about how to value electricity and another choice than the one made here would have given better results.

The research of the biodiesel made of fish oil, shows that it is really important to make use of the by-products in all types of production. When the by-product is used in new production, this both save the resource that would have been used instead and spare the waste-handling. However, it is necessary to include in the evaluation of the waste use, which other options there are for the waste.

When a biofuel such as biodiesel is assumed to be fossil free, it is important to make sure that the same amount of biomass that was taken from the nature is actually grown up again.

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Appendix A

Fertilizer

Calculation of fertilizer used:

$$\frac{130\,\frac{kg\ fertilizer}{ha}}{2466.85\,\frac{kg\ seeds}{ha}} = 0.052699\,\frac{kg\ fertilizer}{kg\ seeds}$$

Biodiesel consumption for rapeseed drying

$2670kg$ rapeseed contents $2670 \cdot 0.15 = 400.5kg$ water.
Without water it would be $2670 - 400.5 = 2269.5kg$ rapeseed
After drying the rapeseed contents 8% water which means that $\frac{2269.5}{0.92} = 2466.85\ kg$ rapeseed is produced per hectare.
$2670 - 2466.85 = 203.15$ liter water are removed. It takes 0.132 liter light fuel oil per liter removed water [9] which is $0.132 \cdot 203.15 = 26.82\,\frac{liter}{ha}$.
$\frac{26.82}{2466.85} = 0.0109\,\frac{liter\ light\ fuel\ oil}{kg\ rapeseed}$

$0.0109\,\frac{liter}{kg} \cdot 36.08\,\frac{MJ}{l} = 0.392\,\frac{MJ}{kg}$. When $36.08\,\frac{MJ}{l}$ is the energy content in light fuel oil [18].
$\frac{0.386}{34} = 0.01\,\frac{liter\ \ biodiesel}{kg\ produced\ rapeseed}$ when $3434\,\frac{MJ}{liter}$ is the energy content in biodiesel [17].

Electricity consumption, fish oil production

Total produced weight:

$0.21kg\ oil + 1kg\ meal\ = 1.21kg\ totalt\ mass$

Electricity consumption for $0.21kg$ is 0.19 kWh.

Electricity consumption for $1kg$ oil produced:

$$\frac{0.21kg\ oil}{1.21kg\ total\ mass} = 0.1736$$

$$0.1736 \cdot 0.19\ kWh = 0.03298\ \frac{kWh}{0.21\ kg\ oil}$$

$$\frac{0.03298\,\frac{kWh}{0.21\ kg\ oil}}{0.21kg\ oil} = 0.16\,\frac{kWh}{kg\ oil}$$

Electricity consumption, biodiesel production

Electricity consumption for the production of one liter of biodiesel:

$$65W \cdot 12h = 078kWh$$

Appendix B

Table 3: Emissions from combusting

Emissions [15]	Light fuel oil (1 MJ)	Biodiesel (1 MJ)
CO	$7.5E^{-6}$ kg	$7.5E^{-7}$ kg
CO_2	0.074 kg	0 kg
NO_x	$2.75E^{-5}$ kg	$2.82E^{-5}$ kg
SO_2	$4.68E^{-5}$ kg	$5.45E^{-5}$ kg

Table 4: Energy content

	Energy content
Biodiesel	34 MJ/l [17]
Light fuel oil	42.7 MJ/kg[18]

Table 5: The flow in the LCA

Flow	Combustion	Biodiesel production	Oil extraction	Growing
Biodiesel Rapeseed Tolefors	1MJ = 0.0294 l biodiesel	1 l biodiesel = 0.92 kg rapeseed oil [2]	1 kg rapeseed oil = 3.28 kg rapeseed [9]	1 kg rapeseed = 3.243 g rapeseed [9]
Biodiesel Rapeseed Belarus	1MJ = 0.0294 l biodiesel	1 l biodiesel = 0.92 kg rapeseed oil [2]	1 kg rapeseed oil = 3.28 kg rapeseed[9]	1 kg rapeseed = 3.243 g rapeseed [9]
Biodiesel Fish oil Norway	1MJ = 0.0294 l biodiesel	1 l biodiesel = 0.92 kg fish oil [2]	1 kg fish oil = 22.2 kg fish[5]	
Light fuel oil	1 MJ = 0.0234 kg light fuel oil			

Appendix C

Table 6: The processes with the largest impacts, Fish oil based biodiesel

Fish oil based biodiesel	Global warming	Ozone layer depletion	Photochemical oxidation
	Electricity, medium voltage	Methanol, at plant/GLO S	Electricity, medium voltage
	Methanol, at plant/	Transport, lorry >32t, EURO4	Light fuel oil, burned in boiler
	Transport, lorry >32t, EURO4	Electricity, medium voltage	NaOH (100%)
	Electricity, low voltage	NaOH (100%)	Transport, lorry >32t, EURO4
	NaOH (100%)	Electricity, low voltage	Methanol, at plant

Table 7: The processes with the largest impacts, light fuel oil

Light fuel oil	Global warming	Ozone layer depletion	Photochemical oxidation
	Light fuel oil, burned in boiler	Light fuel oil, at refinery	Light fuel oil, at refinery
	Light fuel oil, at refinery/RER S	Electricity, low voltage	Light fuel oil, burned in boiler
	Electricity, low voltage	Transport, lorry >16t	Electricity, low voltage
	Transport, crude oil pipeline	Transport, crude oil pipeline	Transport, transoceanic tanker
	Transport, lorry >16t	Transport, transoceanic tanker	Transport, crude oil pipeline

Table 8: The processes with the largest impacts, rapeseed based biodiesel Tolefors

Rapeseed based biodiesel, Tolefors	Global warming	Ozone layer depletion	Photochemical oxidation
	Electricity, medium voltage	Diesel, low-sulphur	Electricity, medium voltage
	Ammonium nitrate, as N	Methanol, at plant	Light fuel oil, burned in boiler
	Tolefors Rape seed conventional	Ammonium nitrate, as N	NaOH (100%)
	Methanol, at plant	Electricity, medium voltage	Diesel, low-sulphur
	Electricity, low voltage	NaOH (100%)	Methanol, at plant

Table 9: The processes with the largest impacts, rapeseed based biodiesel Belarus

Rapeseed based biodiesel, Belarus	Global warming	Ozone layer depletion	Photochemical oxidation
	Electricity, medium voltage	Diesel, low-sulphur	Electricity, medium voltage
	Ammonium nitrate, as N	Operation, lorry >32t, EURO3	Light fuel oil, burned in boiler
	Belarus Rape seed conventional	Methanol, at plant	NaOH (100%)
	Operation, lorry >32t, EURO3	Ammonium nitrate, as N	Operation, lorry >32t, EURO3
	Methanol, at plant	Light fuel oil, at refinery	Road/CH/I S

Table 10: The processes with the largest impacts, Fish oil based biodiesel

Fish oil based biodiesel	Acidification	Eutrophication	Non renewable, fossil
	Electricity, medium voltage	Electricity, medium voltage	Electricity, medium voltage
	Light fuel oil, burned in boiler	Light fuel oil, burned in boiler	Methanol, at plant
	NaOH (100%)	Transport, lorry >32t, EURO4	Transport, lorry >32t, EURO4
	Electricity, low voltage	NaOH (100%)	Electricity, low voltage
	Transport, lorry >32t, EURO4	Methanol, at plant	NaOH (100%)

Table 11: The processes with the largest impacts, light fuel oil

Light fuel oil	Acidification	Eutrophication	Non renewable, fossil
	Light fuel oil, at refinery	Light fuel oil, at refinery	Light fuel oil, at refinery
	Light fuel oil, burned in boiler	Light fuel oil, burned in boiler	Electricity, low voltage
	Electricity, low voltage	Electricity, low voltage	Transport, crude oil pipeline
	Transport, transoceanic tanker	Transport, transoceanic tanker	Transport, lorry >16t
	Transport, crude oil pipeline	Transport, lorry >16t	Transport, transoceanic tanker

Table 12: The processes with the largest impacts, rapeseed based biodiesel Tolefors

Rapeseed based biodiesel, Tolefors	Acidification	Eutrophication	Non renewable, fossil
	Electricity, medium voltage	Electricity, medium voltage	Electricity, medium voltage
	Light fuel oil, burned in boiler	Ammonium nitrate, as N	Methanol, at plant
	Ammonium nitrate, as N	Light fuel oil, burned in boiler	Diesel, low-sulphur
	NaOH (100%)	Rape seed IP,	Ammonium nitrate, as N
	Electricity, low voltage	Diesel, low-sulphur	Electricity, low voltage

Table 13: The processes with the largest impacts, rapeseed based biodiesel Belarus

Rapeseed based biodiesel, Belarus	Acidification	Eutrophication	Non renewable, fossil
	Electricity, medium voltage	Electricity, medium voltage	Electricity, medium voltage
	Light fuel oil, burned in boiler	Ammonium nitrate, as N	Methanol, at plant
	Ammonium nitrate, as N	Operation, lorry >32t, EURO3	Diesel, low-sulphur
	Operation, lorry >32t, EURO3	Light fuel oil, burned in boiler	Ammonium nitrate, as N
	NaOH (100%)	Rape seed IP	Operation, lorry >32t, EURO3

Appendix D

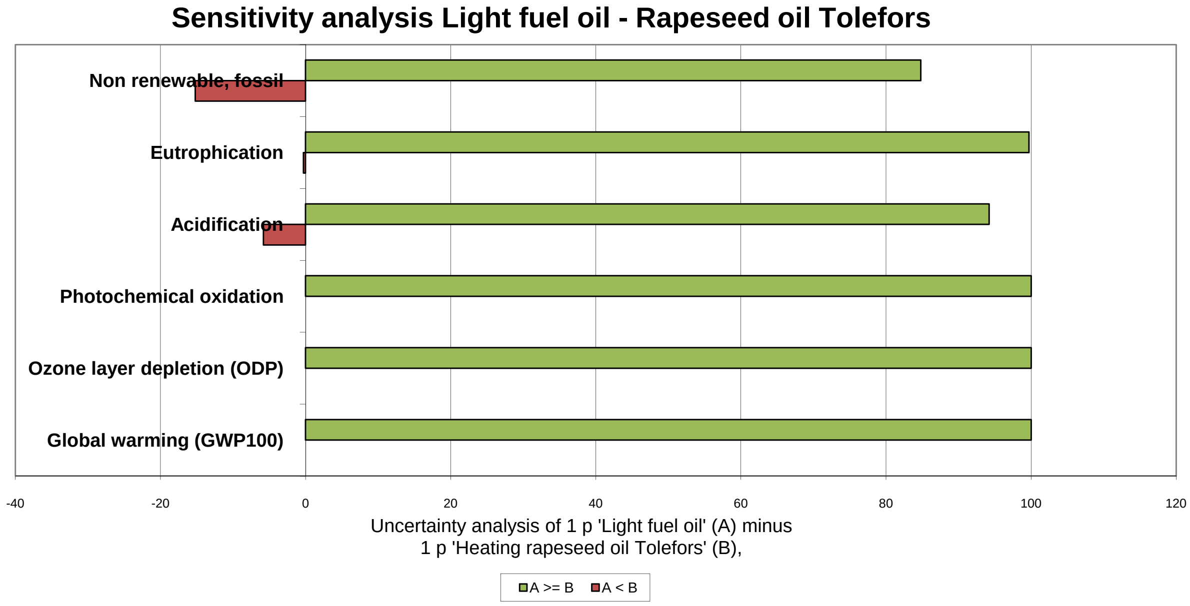

Fig. 13: Sensitivity analysis comparing light fuel oil with biodiesel made from Tolefors rapeseed oil.

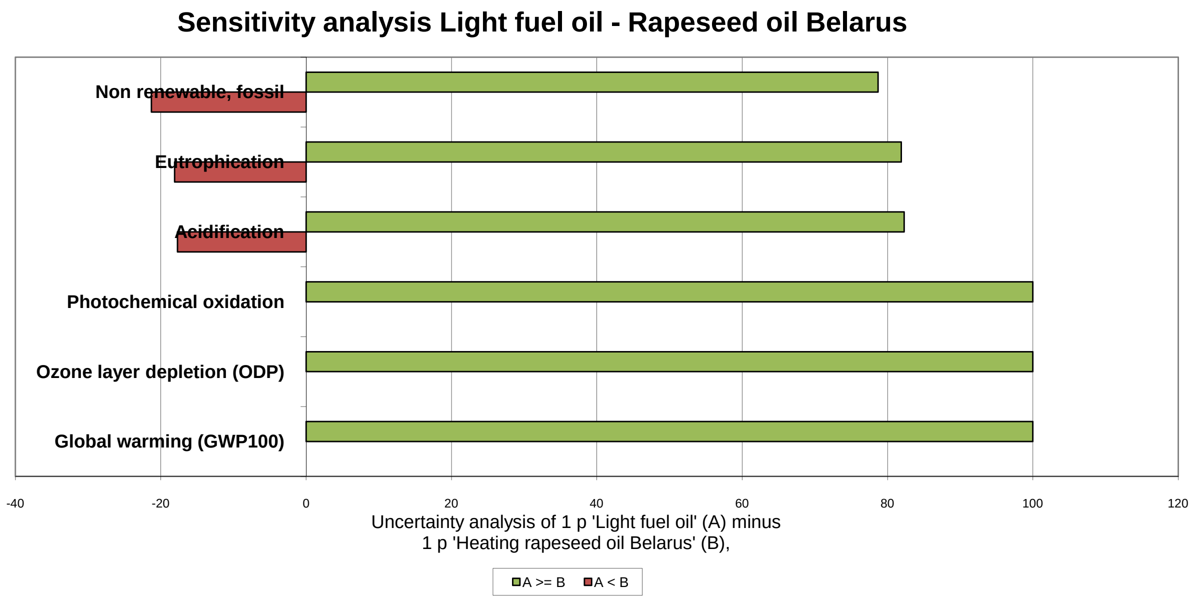

Fig. 14: Sensitivity analysis comparing light fuel oil with biodiesel made from Belarusian rapeseed oil.

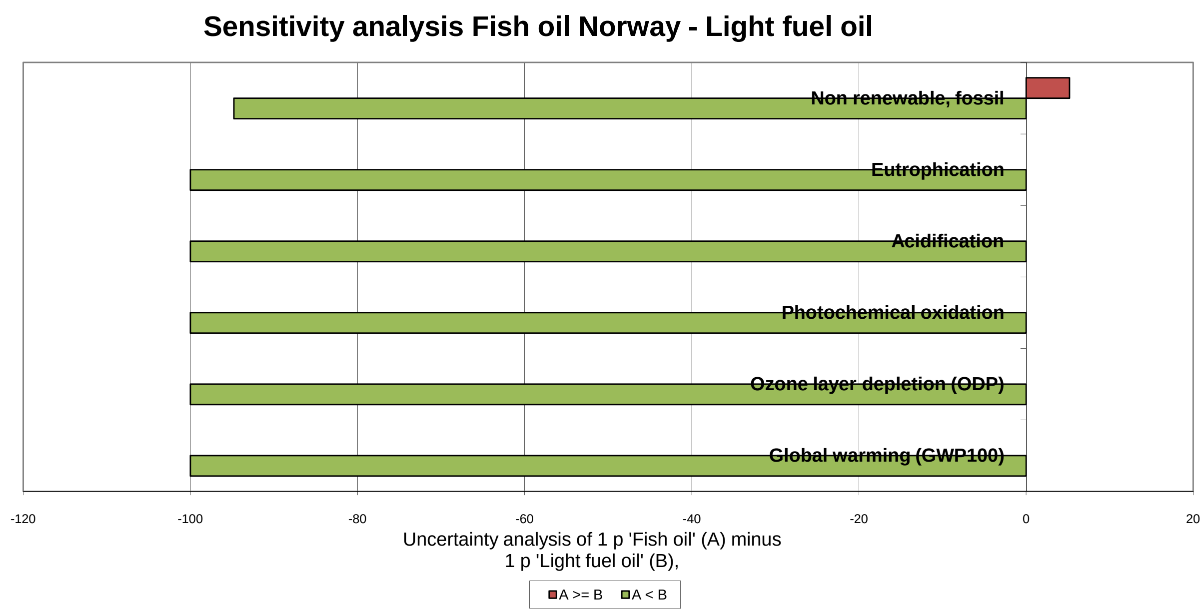

Fig. 15: Sensitivity analysis comparing biodiesel made from Norwegian fish oil with light fuel oil.