How to decrease environmental impact by choice of car fuel

- A comparison of E85 and petrol

Project work, Group 1
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Serina Ahlgren, SLU
Erick Nfon, SU
Rolf Tryman, FOI

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1. Goal and scope

1.1 Goal of the study

Within the course "Advanced course in LCA", a project work is to be conducted. This paper is a result of that. The project work was chosen based on the interest of the participants:

Today most passenger cars in Sweden run on fossil fuels. By combusting fossil fuels the concentration of carbon dioxide increase in the atmosphere, which in turn will lead to a global warming.

The fact of global warming, together with increasing oil prices and the pressure from consumers has lead to that some car manufacturers in recent years have started to sell passenger cars that run on alternative fuels. The most common renewable fuels that are being commercialised are biogas, E85 (ethanol) and RME (rape methyl ester).

E85 is a fuel that consists of 85 % ethanol together with petrol and some other substances. Today the ethanol in Sweden is produced from fermentation of grain, mostly wheat. Some ethanol is also imported from Brazil, originating from sugar cane. In the long run, producing ethanol in this way is not sustainable. Previous life cycle assessment has shown that ethanol from grain has a quite high environmental impact (Bernesson, 2004) and furthermore that it is very expensive to produce. Ethanol from Brazil is today cheap, but not an option to rely on in the future. It is very uncertain that they can deliver the increasing amount of ethanol that the European market is demanding.

A few weeks ago a Swedish plant in Örnsköldsvik started to produce ethanol from sawdust. The production is still in a start up phase, but the optimism is high. In a not so distant future Sweden could become self-sufficient of ethanol from wood and wood residues, which would be a much more sustainable way of supplying ethanol to the Swedish market.

So, if one was to buy a new car today, there are a number of different cars and fuels to choose from. In what way does these choices effect the environmental impact, and especially global warming? **In this paper we will investigate the environmental impact of choosing a car that runs on E85 compared to a car driven on petrol.** The ethanol in the E85 is assumed to be produced from Swedish sawdust.

1.2 Methodology

The study will be conducted using life cycle assessment (LCA) methodology. The LCA will be done with aid of the data base program SimaPro 6.0.

LCA is a tool to identify, quantify and evaluate the environmental impacts involved in the life of a product, process or activity (Heijungs R ed., 1992) This includes identifying and quantifying energy and materials used and wastes released to the environment, calculating their environmental impact, interpreting results and evaluating improvement opportunities. Its main advantage over other site specific methods for environmental analysis such as Environmental Impact Assessment (EIA) lies in broadening the system boundaries to include all burdens and impacts on the life cycle of the system and not focusing on the emissions and wastes generated by a plant or manufacturing site only (Azapegic A. 1999). The final output of the analysis is a set of improvement scenarios that will help reduce the environmental burdens brought on by a product or process. The method for conducting life-cycle studies have been standardized amongst others by the Society of Environmental Toxicology and Chemistry (SETAC) through the Code of Practice (Consoli F et al., 1993) and the International Standards Organization (ISO) through standards (ISO14040, 14041, 14042 and 14043). The methodology put forward by the ISO is the most generally accepted and the ISO guidelines for life cycle assessment divide the procedure into four components as shown in figure 1. This includes

- Goal definition and scoping were a clear definition of the purpose and system boundaries for the analysis is stated.
- Inventory analysis, which refers to the identification and quantification of energy, resource use, and environmental emissions to air, water and land.
- Impact impact assessment, which attempts to translate the inventory data into effects on human health, the environment, and resource depletion.
- Interpretation, which concerns the evaluation and implementation of opportunities to reduce environmental burdens.

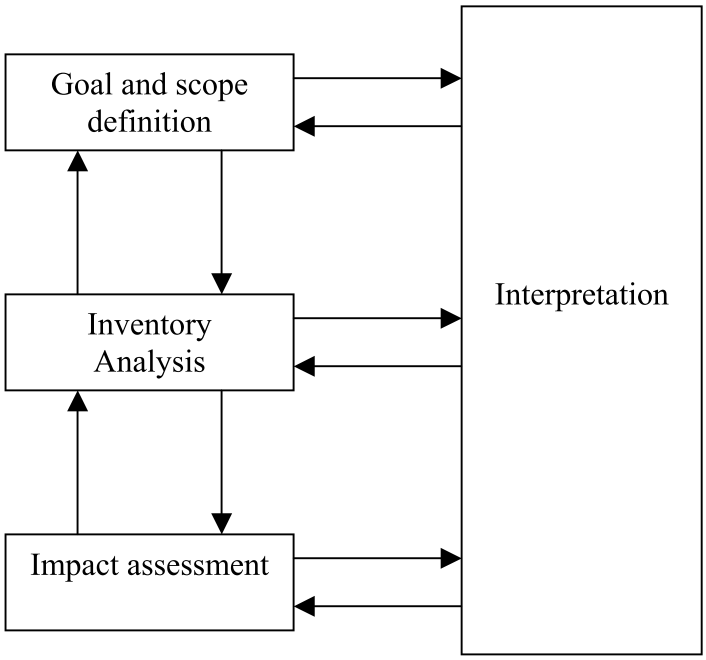

Figure 1. LCA framework according to ISO 14040 (Adapted from ISO, 1997).

1.3 System boundaries

The system boundaries used for this study is based on the flow chart shown in figure 2. The cradle of materials is considered to be nature, raw materials are extracted from nature into the technosphere and the grave of the system is also nature in the form of emissions to air, water and land. In assessing the environmental impacts of the different processes, only potential effects will be considered and not actual effects. As is the common practice in LCA studies, only the direct effect of industrial processes are considered hence the energy and wastes associated with the manufacturing of industrial premises and machinery used to produce the fuels are excluded. The environmental impacts and energy used are assumed to be negligible compared with the amounts of products which the equipement manufactures in its lifetime (Jönsson Å., Tillman, A.M., Svensson, T., 1995)

The E85 fuel is assumed to be produced from Swedish sawdust, but some additives to the fuel is made from imported crude oil.

The time horizon of this study is not completely trivial. We have assumed present day technology considering fuel consumption and motor efficiency for an E85 driven car. However, the E85 marketed at gas stations today is produced from wheat or sugar cane. It will be a few years before wood based ethanol can be on the market at competing prices. Also, the wood to ethanol process is not yet a mature technology, and in the future it is very possible that the process will be much more energy efficient.

System expansion and allocation due to the economic value of by-products was used in this study.

1.4 Functional unit

The functional unit is 100 km driven by a passenger car in Stockholm. The reference flow for petrol is 6,9 litres (5,1kg) and for ethanol 9,2 litres (7,18 kg). These figures are based on the consumption in a Ford Focus FlexiFuel (Miljöfordon, 2005).

1.5 Assumptions and limitations

Since this work only is a part within a course, the extent of the study is limited. Due to the difficulty in collecting relevant data and the time constraints, we had to resort to some assumptions to make this analysis easy to accomplish. The assumptions that were chosen are further explained in section 2.3

1.6 Chosen impact categories and impact assessment method

The aim of the impact assessment step in an LCA study is to aggregate the inventory data into a single parameter so that the environmental significance can be better understood.
In the present study the CML method (Heijungs, 1992) was chosen as the impact assessment method. Impact assessment in LCA consists of the mandatory elements classification and characterization and the optional elements normalization, grouping and weighting (ISO 14042). In the present study, only the mandatory elements of classification and characterisation were used and the following environmental problems were investigated: global warming potential, acidification potential and eutrophication potential.

Global warming potential
The increasing temperature in the lower atmosphere is termed global warming or the green house effect. Certain gases for example carbon dioxide, methane, water vapor, nitrogen oxides and some halogenated hydrocarbons absorb thermal radiation emitted from the surface of the earth which means that not all radiation emitted from the earth surface reaches outer space. This redirection of thermal radiation is referred to as the greenhouse effect and is the major cause of global climate change or global warming (Jensen et al., 1997). In the calculation of the global warming potential, the inventory results of both fuel types

contributing to global warming was expressed as kilograms of carbon dioxide equivalents using the default global warming potentials in CML method, i.e.:
Global warming potential (kg of CO_2 equivalents) = $\Sigma_i GWP_i * m_i$
Where GWP_i is the global warming potential for gas i and m_i is the mass (kg) of gas i emitted from the activity.

Acidification
Acidification is caused by the release of protons in the terrestrial or aquatic ecosystems. Acidifying substances either supply or release hydrogen ions in the environment or leach the corresponding anions from the environment. The main gases contributing to acidification are for example, sulphur dioxide, nitrogen oxides hydrogen chloride etc. In the characterisation step the emissions in the inventory results that contribute to acidification were multiplied by their corresponding acidification potentials. Finally the potential contribution to acidification was obtained by summing the individual contributions.
Acidification potential (kg of SO_2 equivalents) = $\Sigma_i AP_i * m_i$
Where AP_i is the acidification potential for gas i and m_i is the mass (kg) of gas i emitted from the activity (Jensen et al., 1997).

Eutrophication
The presence of surplus nitrogen, phosphorus and degradable organic substances leads to the increased production of algae and higher aquatic plants which causes nutrient enrichment or eutrophication of aquatic systems. The compounds in this group include emissions to air of nitrogen oxides and ammonia to air, and emissions to water of organic substances that require oxygen for their degradation (COD), ammonium ions (NH_4^+), nitrate (NO_3^-) and phosphates (PO_4^{3-}). These compounds are converted to phosphate equivalents using the eutrophication potentials given below
Eutrophication potential (kg of PO_4^{3-} equivalents) = $\Sigma_i EP_i * m_i$
Where EP_i is the eutrophication potential for compound i and m_i is the mass (kg) of compound i emitted (to air or water) from an activity (Jensen et al., 1997).

Photochemical oxidation
Ozone is formed in the presence of NOx and sunlight in the atmosphere. The amount of formed ozone depends mainly on how much nitrogen oxides and organic compounds the atmosphere contains. Increased levels of ozone may cause photochemical smog with effects on human health and ecosystems.

1.7 Normalisation and weighting

No normalisation or weighting was conducted in this study.

2. Life cycle inventory analysis

2.1 Principle process flowchart

The process flowchart is illustrated in Figure 2.

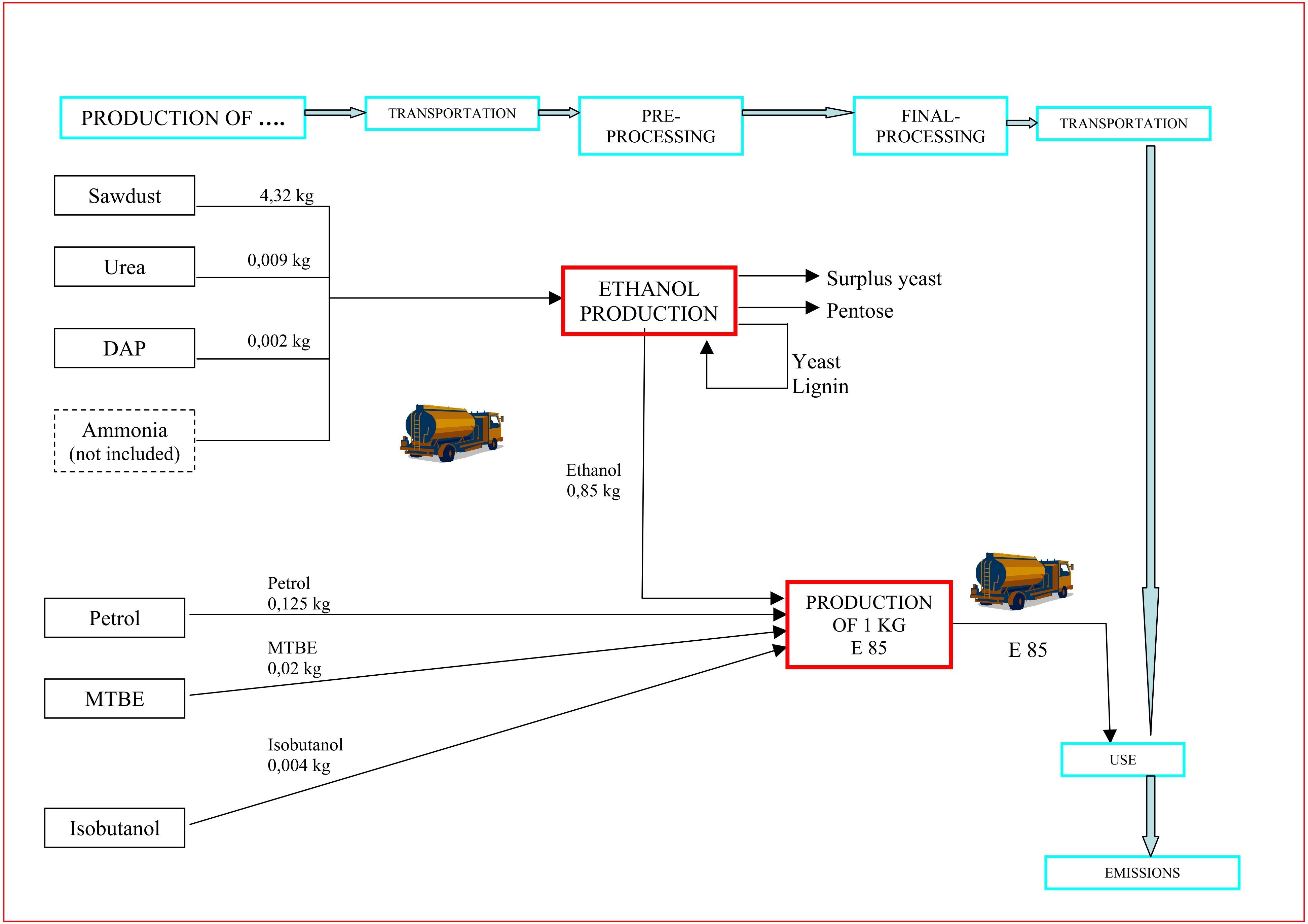

Figure 2. E85 inventory

2.2 Production of E85

E85 consist of 85% ethanol. The most common way to make ethanol today is by fermenting biomass consisting of starch or sugars, for example wheat or sugarcane. There are several methods to make ethanol from cellulose biomass. In our study we use the enzymatic hydrolysis method, which breaks down the cellulose to sugars. The sugars are then fermented to ethanol, and the ethanol is after that purified through distillation. The by-products from the process, pentose and yeast, can be sold as animal feed (Fu, 2005).

In the production of E85, the ethanol is mixed with petrol, MTBE and isobutanol, to make it suitable for use in a combustion engine. The finished product is then transported from the production site to a filling station in Stockholm for distribution. We assumed a transportation distance of 500 km by truck.

2.3 Data

Data for the production of sawdust, urea, MTBE and diammoniumphosphate (DAP) were taken from the Sima Pro database (table 1). Energy use and emissions for production of yeast and isobutanol was taken from Bernesson, 2004. The flow of material in the ethanol production (shown in figure 2) was calculated from Fu, 2005.

Table1.Data from SimaPro.

	Database
Sawdust	Ecoinvent system process
MTBE	ETH/ESU process database
DAP	Ecoinvent system process
Urea	Ecoinvent system process
Transportation	Ecoinvent system process
Electricity mix	Ecoinvent system process

The Sima pro database contains sawdust produced from different sources, but since the final product will be used in Sweden we selected sawdust prepared from Scandinavian softwood (plant barked u=70%)/NORDEL S). The processes included are; debarking and the further production of sawn timber, wood chips and sawdust in a Scandinavian sawmill. The transport of the wood from the forest road to the sawmill is included.

The multi-output process "sawing / debarking, scandinavian softwood, at plant" delivers the coproducts:

- sawn timber, scandinavian softwood, raw, plant-debarked, u=70%,at plant
- chips, scandinavian softwood (plant-debarked), u=70%, at plant
- sawdust, scandinavian softwood (plant-debarked), u=70%, at plant

The allocation is based on the prices of the different outputs.

There is no information in SimaPro about density and moisture content of the sawdust, so we assumed a density=267 kg/m^3 with moisture content of 10% (Woodgas, 2005).

The E85 specifications are described in table 2. The emissions from producing and distributing the additives to E85 are specified in table 3. Table 4 describes the emissions of using E85 in a light duty vehicle.

Table 2. E85 – Ethanol Fuel specification

Content	**Weight%**	**Volume%**	**Density g/cm^3 at 20° C**	**Heat of combustion MJ/kg**	**Heat of combustion MJ/l**
Ethanol	85.0	84.1	0.789[a]	29.7[a]	23.43
MTBE	2.1	2.2	0.741[a]	38.2[a]	28.31
Isobutanol	0.4	0.4	0.802[a]	36.0[a]	28.87
Petrol, 95 oktan	12.5	13.3	0.735	44[b]	32.34
E 85	100.0	100.0	0.78	31.68	24.75

[a] Fraunhofer, 2001
[b] Uppenberg et al, 2001

Table 3. Emissions during production and distribution

Emission to air g	Petrol[b] From 1MJ	Petrol From 1 kg	Isobutanol[c] From 1 kg	Yeast[c] From 1kg
Energy used, electricity, MJ	-	-	0.04	0**
Energy used, steam, MJ	-	-	0.5*	0**
NO_x	0.033	1.45	1.27	1.66
SO_x	0.020	0.88	0.44	1.17
CO	0	0	0.028	0.165
NMVOC	0.041	1.80	3.91 (HC)	0.034 (HC)
CO_2	40.0	1760	735	280
N_2O	0	0	0	-
CH_4	0.002	0.088	0.0243	0.00024
NH_3	-	-	-	0.014
Particles	0.0011	0.048	0.064	0.077

[b] Uppenberg et al, 2001
[c] Bernesson, 2004
* 0.5 MJ steam is equal to 0.22 kg steam assuming main part is condensation energy.
** The described emission values for yeast include emissions from energy use.

Table 4. Emissions from the use E85 (Uppenberg et al, 2001).

Emission to air, g/kg	E85
NO_x	0.57
SO_x	0.063
CO	9.82
NMVOC	0.66
$CO_{2\ \text{from fossil}}$	523
$CO_{2\ \text{from biomass}}$	2962
N_2O	0
CH_4	0
Particles	0.057

We had difficulties finding data about the energy consumption during the ethanol process. In the end we made the assumption that the lignin (which is the woody part of the sawdust that can not be processed to ethanol) is used as a feedstock for the heat and electricity needed. The ethanol process is in other words self-sufficient on energy. This assumption can seem a bit rough, but in fact it may not be such a bad guess. In a study by Lund university (Zacchi et al, 2005) the most energy-demanding process is steam for evaporation and distillation, corresponding to 6,28 MW of electric power. For these requirements, Zacchi et al state that almost all lignin is needed. In a well-to-wheel analysis conducted by the Swedish National Road Administration (Ahlvik & Brandberg, 2001), it is also confirmed that only a small amount of excess lignin can be expected from a wood to ethanol plant.

The by-product pentose is allocated on economical basis (12% of the value of the produced ethanol), while the yeast was accounted for by system expansion, see table 3.

It was assumed that transport from one process location to the other is by truck. Inventory was accounted for by identifying the load and the distance traveled, 500 km between Örnsköldsvik and Stockholm.

When comparing E85 with petrol, we use data for the whole petrol life cycle, see table 5.

Table 5. Total impact assessment from petrol, including combustion in light duty vehicle. (Uppenberg et al, 2001)

Emission to air g	Petrol[e] From 1 MJ	Petrol From 1 kg
Energy used, MJ	0.10	4.4
NO_x	0.068	2.99
SO_x	0.030	1.32
CO	0.180	7.92
NMVOC	0.069	3.04
CO_2	79.0	3480
N_2O	0.020	0.88
CH_4	0.009	0.40
Particles	0.0045	0.20

While constructing our E85 life cycle in SimaPro, we realised that the sawdust gave us large minus in global warming. In other words, the growing of trees was looked upon as carbon dioxide uptake.

But since we are burning the E85 (and all the lignin during ethanol production), hence releasing carbon dioxide, the same amount of carbon that was taken up by the trees is emitted during the process and using phase.

3. Life cycle interpretation

3.1 Results

We will first explain how the E85 contributes to the different impact categories and then compare to the petrol scenario. During the work it was clear that the data for photochemical oxidation was not complete. A fair comparison can therefore not be made and that impact category is excluded.

Global warming potential

As shown in figure 3 and 4 below, the main activity making a significant contribution to the global warming in the E85 life cycle is the use phase, and the single important contributor is carbon dioxide. This is rather obvious since combustion processes always generate carbon dioxide and other gaseous substances that contribute to global warming. But since the ethanol used in E85 was generated from biomass, a similar amount of carbon dioxide was taken up by he trees from which the sawdust was generated. Hence there was no net excess carbon dioxide emission from the use of ethanol in E85.

Figure 3 shows that the net contribution to global warming (in kg CO_2 equivalents) for E85 is positive (6.76 kg of CO_2 equivalents). The processes making a contribution are transportation of E85, use of E85 and the production of MTBE, the contribution from the production of isobutanol was rather insignificant. The contribution from the use of E85 and the production of MTBE is CO_2 from fossil fuels used in the petrol additive and fossil fuels used in the production of MTBE. The contribution from isobutanol is insignificant due to the fact that only a very small amount of isobutanol is used in the production of E85 (less than 0.03 kg/Functional unit E85).

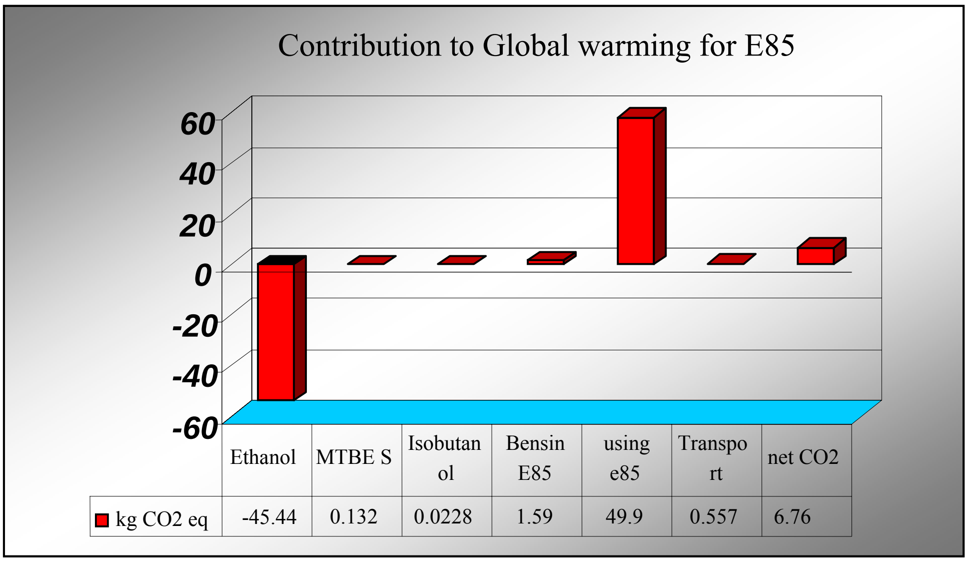

Figure 3. Contribution to global warming potential for the different ingoing substances in E85.

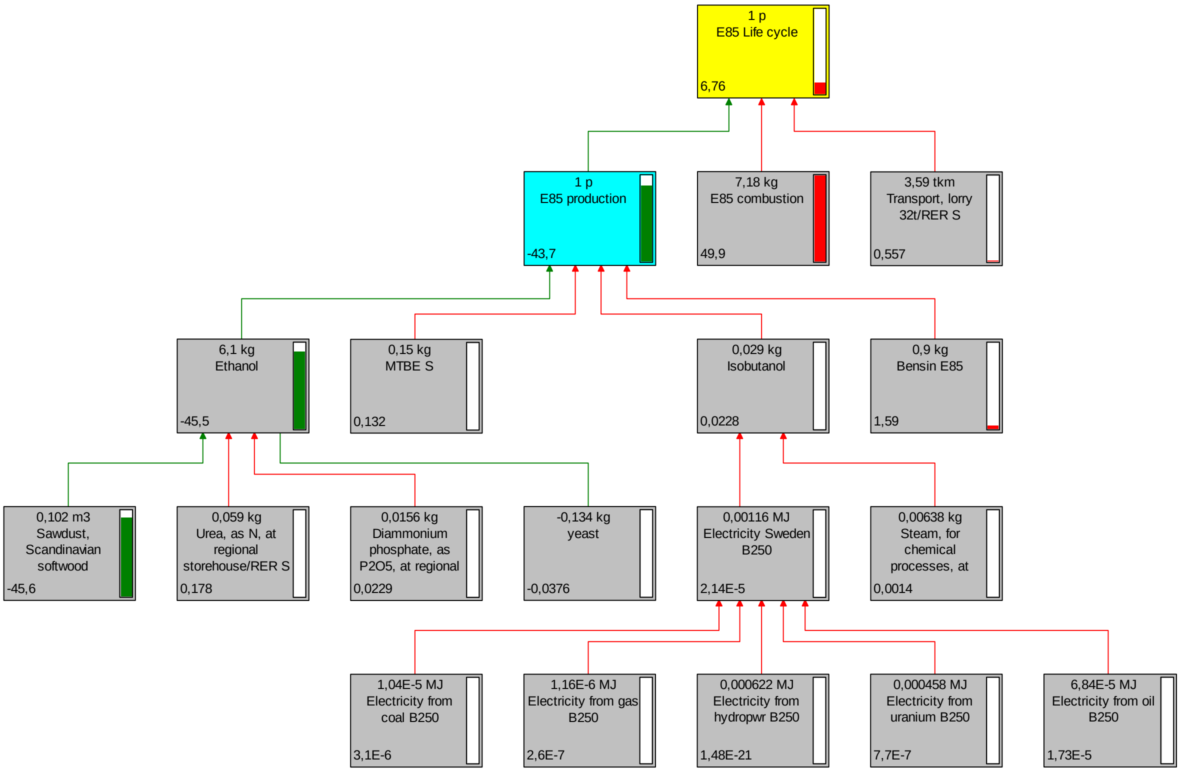

Figure 4. Global warming potential. The numbers in the lower left hand corner of the boxes shows kg of CO_2-equivalent.

Acidification potential

As seen in figure 5 and 6, the largest single contribution to acidification is the transportation of the fuel from Örnsköldsvik to Stockholm. The production of sawdust and the combustion of E85 also have a large impact. The impact of yeast is negative since the ethanol production gives as surplus of yeast. That yeast can be used in another production chain outside our system, and so it is a case of avoiding producing yeast somewhere else.

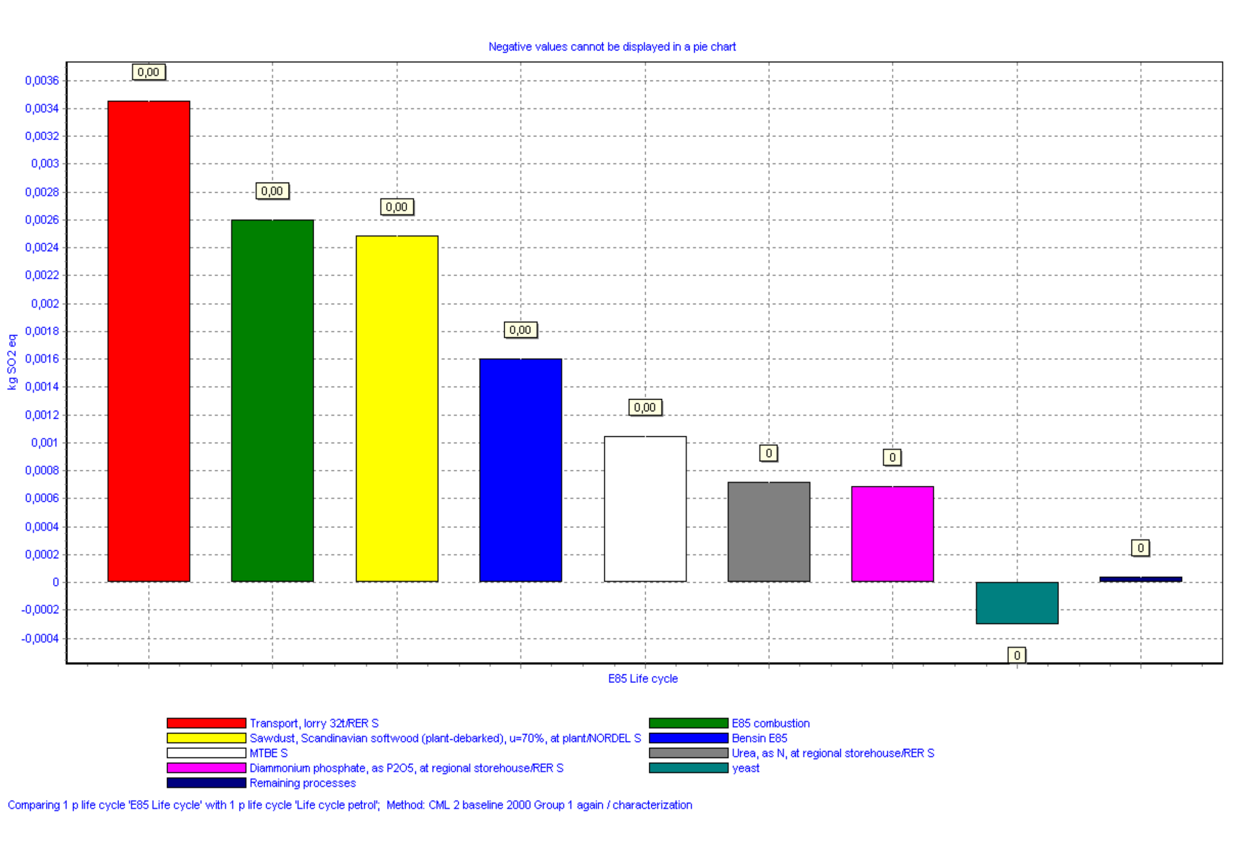

Figure 5. Contribution to acidification potential for life cycle of E85.

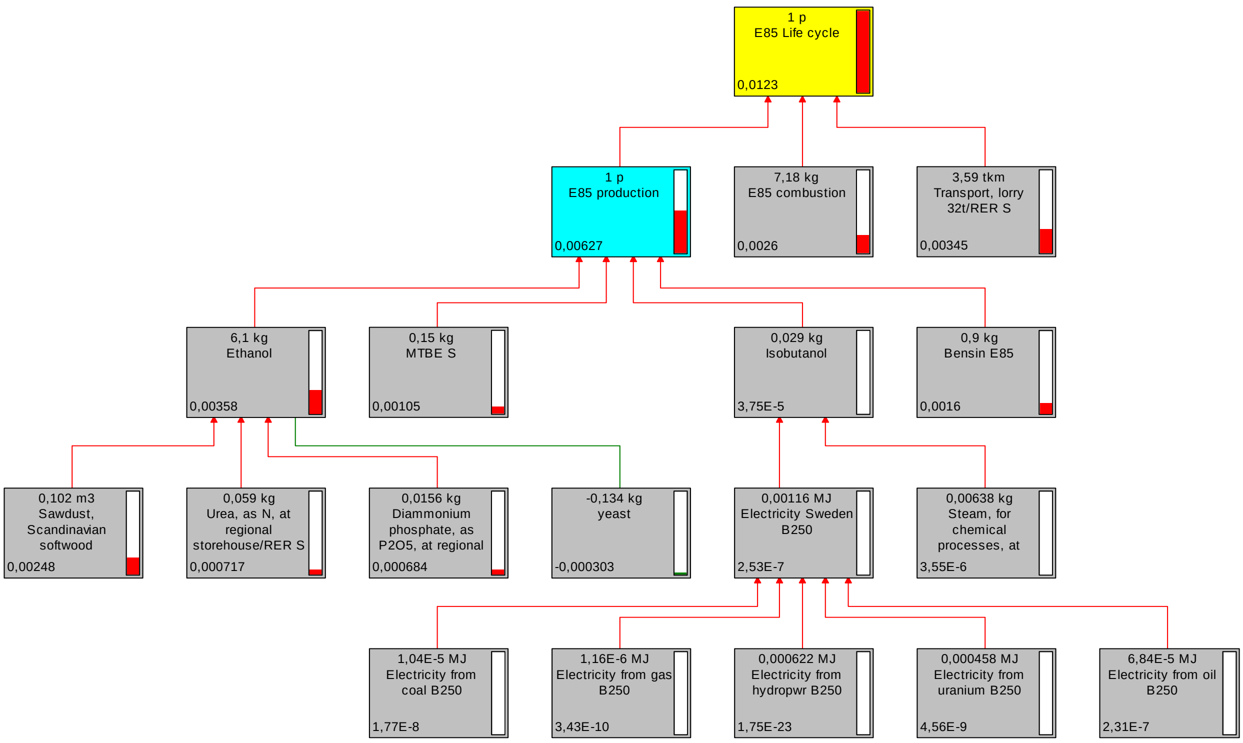

Figure 6. Acidifying potential. The numbers in the lower left hand corner of the boxes shows kg of SO_2-equivalent.

Eutrophication potential

The largest contributors to eutrophication in our system are the production of diammonium phosphate, production of sawdust and the combustion of E85 (figure 7 and 8). Yeast still give a small negative value as in the case with acidification.

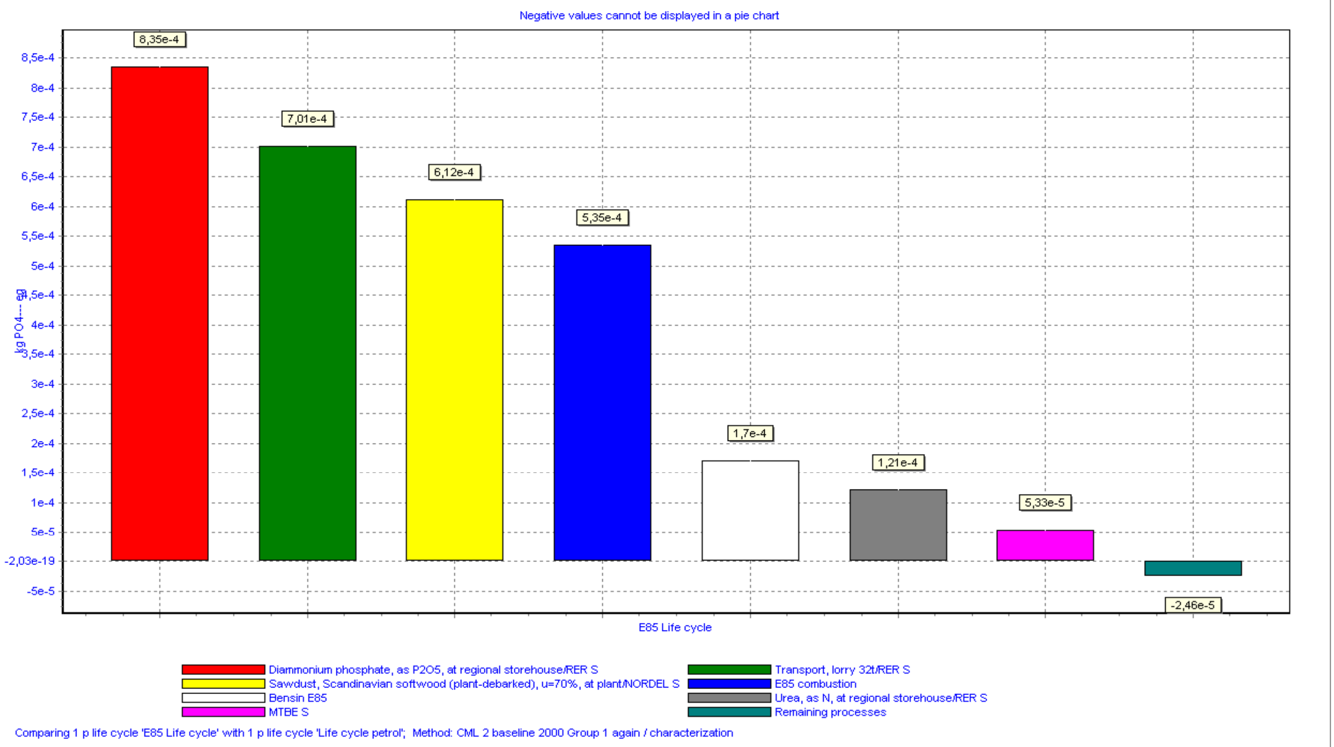

Figure 7. Contribution to eutrophication potential for the life cycle of E85.

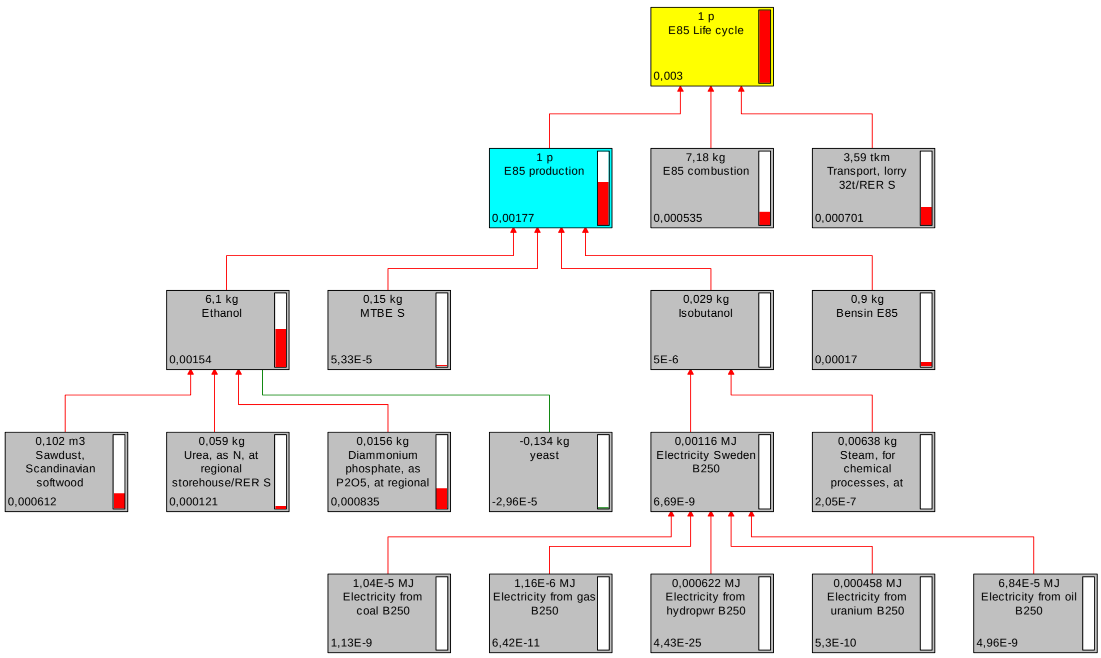

Figure 8. Eutrophication potential. The numbers in the lower left hand corner of the boxes shows kg of PO_4-equivalent.

E85 vs. petrol
Figure 9 below shows the characterisation results for the comparison of E85 and petrol using the CML 2 baseline 2000 method. As is evident in the figure, E85 gave lower impacts for global warming potential and acidification potential. Due to lack of data, the photochemical oxidation should not be over interpreted.

In the comparison between E85 and petrol the global warming potential from E85 is much less, which was expected. The fact that E85 give a contribution 35% of petrol is due to transports and production of E85 an also because it contains 12.5% petrol of fossil origin.

Eutrophication is slightly higher for E85 compare to petrol, about 3%. Main reason is the use of diammonium phosphate (DAP) in production of ethanol. The NO_X contribution from petrol is much higher during combustion than E85, but since it has only 1/8 generic eutrophication equivalents of phosphate it does not effect the results as much as the DAP.

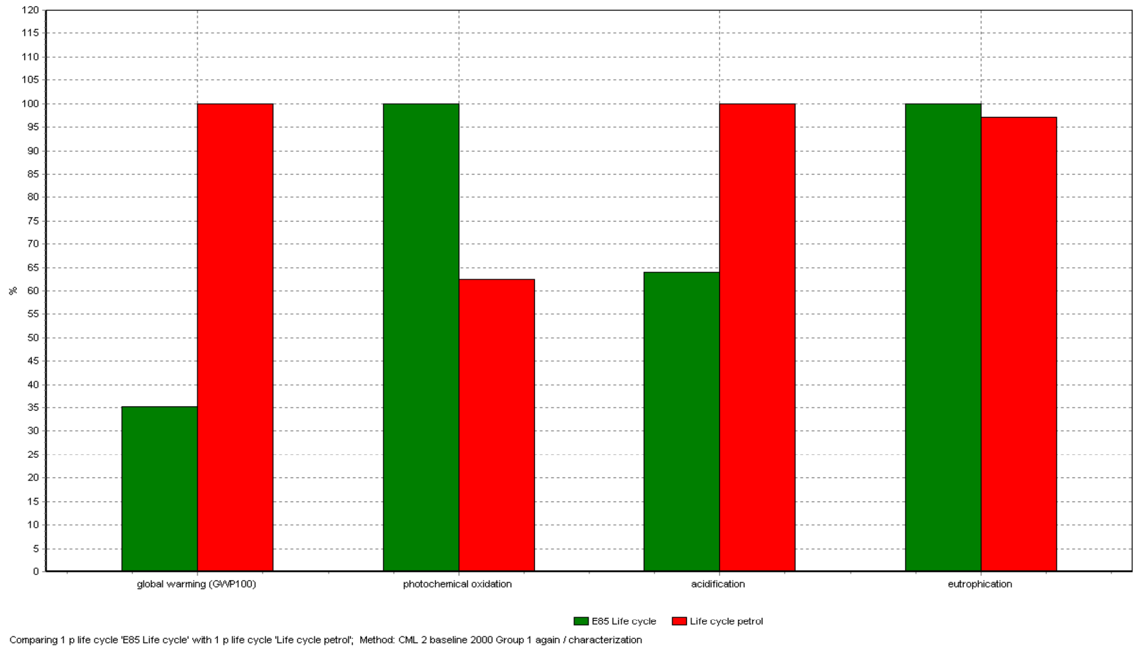

Figure 9. Life cycle of E85 and petrol

Energy balance
One of the parameters frequently used in the literature to determine whether a fuel is renewable is the Net Energy Value (NEV) (Niven, 2005) which compares the amount of energy produced by a litre of a fuel to the energy it takes to produce the fuel from a given process. Two camps of authors has developed, one claiming that the NEV for ethanol is greater than one and the other saying that it is less than one. The trouble comes in defining the values of energy that should be used and what energy inputs are relevant (The energy blog, 2005).

Due to lack of time we did not have the opportunity to calculate the energy balance for our model.

Data quality
Our LCA relied on data reported in reports on investigation of the E85 manufacturing process and that available in Sima Pro. The best data available were used for the parameters that contributed most to the environmental impact, and in cases were there were data gaps, we made informed assumptions that we thought were reliable. The conclusions were reached after aggregation of the data so that we are looking at the total system rather than the contribution from a single parameter.

3.2 Conclusions and recommendations

As seen in figure 9, E85 performs better considering global warming and acidification. E85 gives a little higher contribution to eutrophication than petrol. However, this difference is very small, and considering the margin of error we have in our study, no conclusions can be made from such a result.

As noted earlier, we were unable to find reliable data for the amount of energy used in the production of ethanol. For the production of E85 we assumed the process is self reliant on the energy generated from the lignin. In a commercial future plant however, a surplus of lignin will most likely appear as the process becomes more efficient. The lignin can be sold as a by-product, or used to generate steam or heat for sell. The environmental impact as well as the energy balance for E85 would in such a system be much improved.

From our mass balance we saw that we need a large amount of sawdust (indirectly) from trees to get a litre of ethanol. This implies we need a large area of land to produce a significant amount of ethanol. This land has to be prepared (planting, using insecticides, fertilizers etc). Of course it is always difficult to assess land use in LCA but we think it is worth mentioning. Organic growing practices and advances in technology can help produce ethanol (E85) in a more sustainable way.

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