ECOTRAFFIC ERD3 AB
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LCA – Renewable Energy Directive

Investigation of how the outcome of a LCA study change when the method proposed in the Renewable Energy Directive (2009/28/EC) is used compared to when a custom method that is applied for most LCA's today is used.

In this study the LCA outcome, calculated with two different methods, for four biomass derived transportation fuels, have been compared. The calculation method for LCA in the Renewable Energy Directive (2009/28/EC) is based on energy allocation. While LCA normally, as in ISO 14040, is based on system expansion.

There is no big difference for the alternatives. Not using system expansion will though reduce motivation for positive technical development.

1. Goal and Scope

In this study we investigate how the described environmental impacts in a life cycle perspective change with assumptions according to what is proposed in the Renewable Energy Directive (2009/28/EC) compared to how most LCA studies are performed today. Roughly, the RED directive, which in itself is not intended to be a guide for life cycle assessment but a legal regulation, is based on energy allocation, whereas most LCA studies performed today use system expansion, since this is the recommendation in the ISO 14040- series standard on life cycle assessment.

To illustrate how the two methods affect results we have compared four liquid biofuels produced or planned to be produced in Sweden. The four fuels are ethanol from wheat in the NEAB plant, RME from rape seed by Perstorp, diesel from tall oil by SunPine and Preem, and DME from black liquor by the method developed by ChemRec. As far as possible we base our study on published, open information.

There are differences in the present status of the biofuels studied that must be taken into account when comparing results. The wheat ethanol and REM are produced today, the tall diesel is comparatively close to commercial production, and for the DME there is a demonstration plant but commercial available DME fuel is somewhat further into the future. The ethanol and RME represents what is often referred to as first generation biofuels, the tall diesel and DME represents second generation.

Life cycle assessment studies results are often very sensitive for real world changes. For biobased fuels an easy to understand example is that the yield of e.g. an agricultural area may vary rather dramatically between years depending on the weather situation a specific year. The results for the life cycle assessment will thus only describe e.g. the weather situation under which the study is performed.

In this study we have strived to equalize the situation between the biofuels included in the study, but the main focus of the study is not the exact comparison of the different alternatives but to investigate how different methodological regimes will influence outcome.

The goal of this study is to illustrate the different methodological regimes. Thus we have chosen to describe the processes per MJ of fuel produced, excluding the use phase. Since e.g. different engines will be needed for different fuels, the use phase will include differences between the fuels that might distract from the purpose of this study - how results may vary due to methodological decisions. The main goal is to compare how such impacts influence the outcome for the different fuels, not to compare the different fuels.

2. System expansion vs. Allocation

The main difference between standard practice in LCA and the calculation method in the RED is used in LCA is that the ISO standard recommends system expansion as first choice in the case of multiple input or output processes, whereas the RED prescribe energy allocation. It should be said that the ISO standard does not exclude energy allocation as method, but do recommend system expansion if possible and most LCA studies are preformed this way. This means that results according to LCA studies generally available might differ from results based on the RED prescribed calculation methodology.

The LCA studies have the ambition to describe all consequences in the society. An explanatory example could be a process where a biofuel is obtained and at the same time we obtain nitrogen containing residue stream. If the nitrogen containing stream successfully can be used as fertilizer and thus replacing artificial fertilizer need at a farmer, LCA studies generally account for this by withdrawing the emissions from the fertilizer production no longer necessary. This method is referred to as system expansion.

Using the calculation method prescribed in RED the environmental impact from the biofuel production unit should instead be divided into one part ascribed to the fuel and one part to the nitrogen containing stream, and this partitioning should be based on the energy contents of each stream. Potentially, the results in this case might be very different, since the nitrogen containing stream might have a rather low energy contents (such streams can be low in biomass and high in water) whereas the production of commercial nitrogen fertilizer that the stream can replace is a rather energy intensive process that also emits nitrous oxide. There are thus situations where allocation might underestimate the benefits for the total society by a specific process (but it is of course not necessarily so).

System expansion on the other hand, has the drawback that we don’t actually know if the modeled situation will actually occur since it often is a model of changes that is not directly influenced by the same decisions makers as the choice of technology et.c.

3. Data and grouping of life cycle phases

This study is based on available literature data regarding the four biofuels. The data describes a present situation for the existing biofuel production routs and a more theoretical situation for the biofuels not yet in commercial production.

In the literature different scenarios regarding process routes, technology or implementation are often studied, which of course will give different outcomes for each scenario. To focus on impacts due to different methodological regimes, not every one of these scenarios are included here. We have to some extent streamlined the results from the different studies to make them as comparable as possible when it comes to different raw materials and fuels.

The activities involved in the life cycle of each of the biofuels are grouped into four life cycle phases: cultivation of the biomass (green in diagrams), production of the biofuel (orange), transports & distribution (blue) and avoided emissions from system expansion (yellow).

4. Ethanol from Wheat (NEAB)

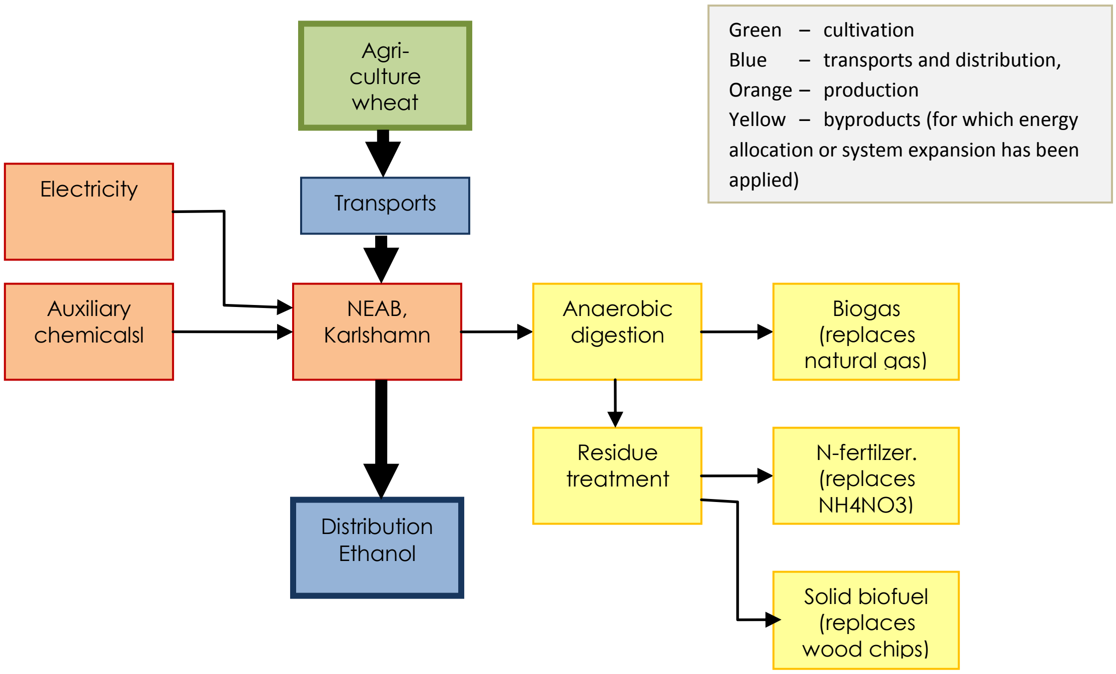


Figure 1. Overview of main activities in the product system for ethanol production. Wheat is fermented and ethanol is recovered by distillation. The water phase is digested to produce biogas, and from the sludge nitrogen fertilizer products are obtained. The solid residue is utilized as a solid biofuel.

There are several possible process designs for ethanol from wheat when it comes to how the residual stream after the ethanol production will be utilized. Here, one of them of them is showed in Figure 1.

Data for the comparison is mainly based on data from Rydberg and Åströms report [1]. The impacts from cultivation are based on wheat from the Baltic Sea region, as described in the EU/JCR Well-to-wheel study. The impacts from production are based on the NEAB production site. Transports include wheat transportation by truck and ship (assuming wheat not only from Sweden but also the Baltic Sea region).

Ethanol is produced at NEAB in Karlshamn, using electricity (described as Swedish average) and a number of auxiliary chemicals whose upstream impacts are included for the major streams; some are used in significant amounts (notably nitric acid).

The residue from the ethanol production is in this scenario sent for anaerobic digestion for production of biogas (replacing natural gas in system expansion case). From the residual sludge nitrogen fertilizers are recovered from the water phase (replacing commercial N-fertilizers in the system expansion case) and the solid phase is used as a biofuel (replacing wood chips in the system expansion case).

5. RME from rape seed

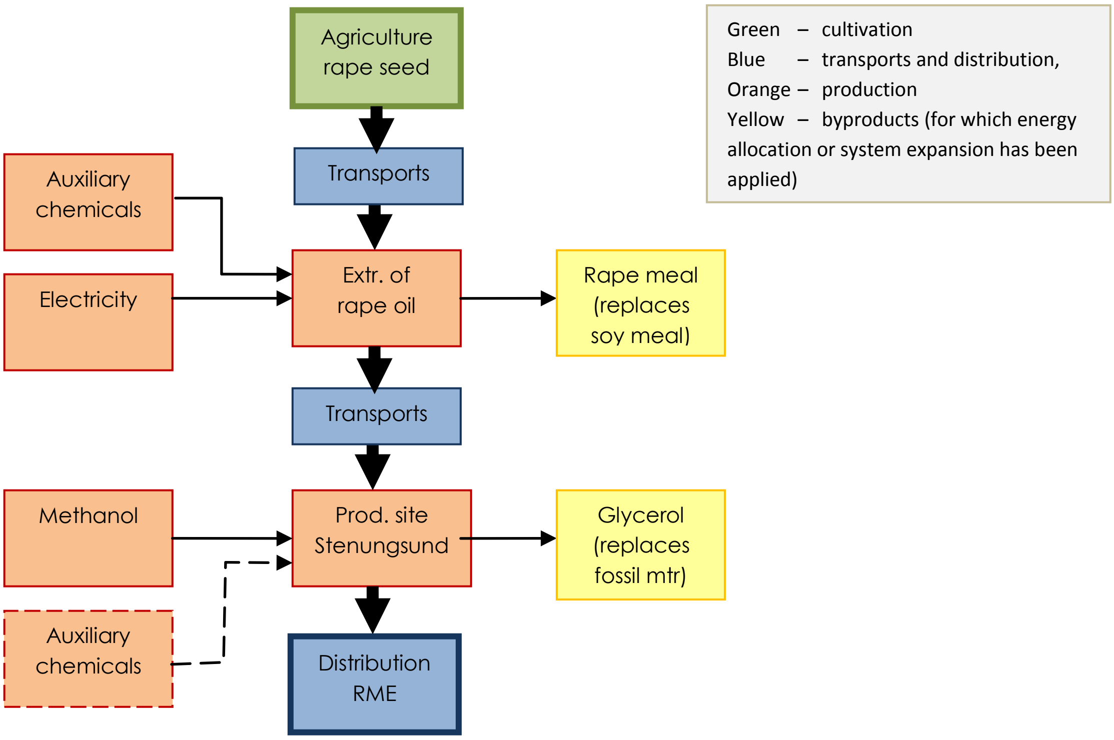


Figure 2. Overview of main activities in the product system for RME production. RME is produced through estrification of rape seed oil with methanol, in this case of fossil origin, but in future potentially produced from biomass. The oil production generates a solid byproduct that can be used as fodder for husbandry animals. The RME production generates glycerol as a byproduct that can be used as raw material in e.g. chemical industry.

Data for the comparison is based on Mårtensson et al [2], recalculated to also describing the energy allocation case in this way. The impacts from cultivation are based on rape cultivation in Denmark. A mix of pure pressing and pressing followed by hexan extraction is used for the description of the rape seed oil production. Electricity mix for each country is applied. Some small flows of auxiliary chemicals used are included in the study. The rape meal residue is considered to replace fodder for husbandry animals, described as a mix of soy meal and barley, in the case of system expansion.

Estrification takes place in Stenungsund. Methanol is described as produced in Norway from natural gas. Some small amounts of auxiliary chemicals use have been disregarded. Glycerol is a byproduct that is assumed to be used for chemicals production. In the case of system expansion 50% of the generated amount of glycerol is considered to replace fossil raw materials wheras the other part is considered to compete with other bioglycerol generation and thus not give any net benefit in society.

6. Pine diesel

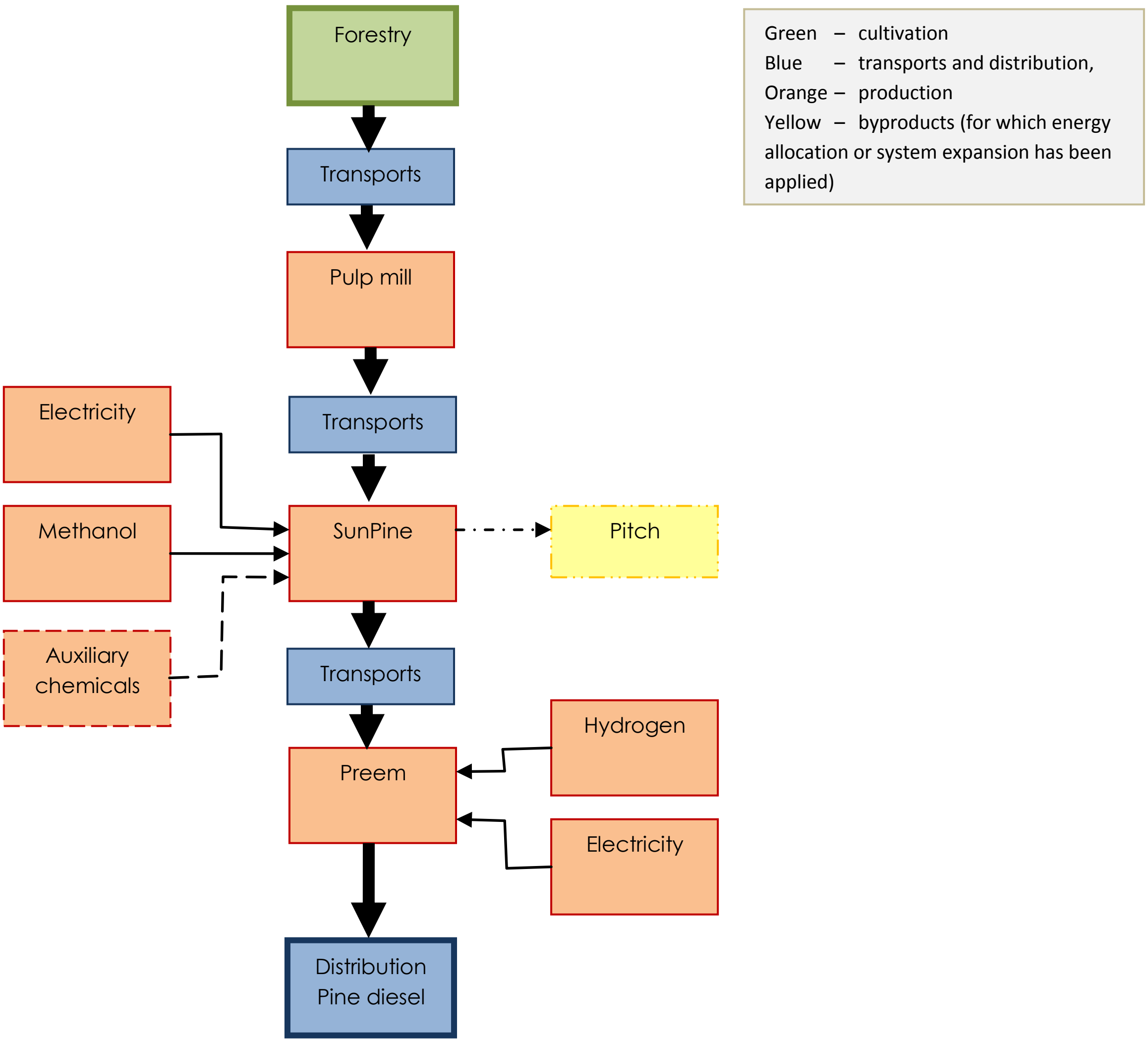


Figure 3. Overview of main activities in the product system for Tall diesel production. Pine diesel is produced from tall oil , a product beside pulp from sulfate paper mills. The tall oil is refined in a first step to a FAME through esterification with methanol by SunPine. The FAME is in a second step hydrogenated into a diesel fuel by Preem. The tall oil is today used as raw material for chemicals production. The refining of the tall oil to FAME generates a tall oil pitch that is considered to be sent back to the pulp mill to use for energy purposes.

There is also some lighter hydrocarbons and oxygenates formed in the SunPine process. This material is used as an internal fuel. The hydrogenation generates a fuel gas (used internally for energy purposes at the refinery) and surplus heat.

Data for the comparison is based on Well-to-Wheel [3], but recalculated using additional information to be comparable with the other fuels described in this study, and to generate the system expansion results. Forestry and pulp mill operations are based on data from Södra and considering three different pulp mills producing tall oil. Environmental impacts for this part are allocated between pulp and tall oil based on energy contents.

Electricity use at SunPine (and also at Preem) is described as Swedish average electricity. Methanol is of renable origin. Some auxiliary chemicals (H_2SO_4, KOH etc) are used, but in very small amounts compared to the methanol, and have been disregarded. Parts of the tall pitch and some energy rich gases produced are considered to be used at SunPine to cover internally energy needs.

The description of the raw tall diesel / FAME production does not take into account that the tall pitch byproduct, all is considered to be used at the production site. This has for comparability been adjusted (assuming 1% of the tall oil energy content is assumed to be needed for internal heat needs at SunPine).

The raw tall diesel / FAME is transported to Preem where it is entered into the hydrogenation unit in the refinery. Regarding Preem, no changes are considered to occur for other streams in the refinery when the raw tall oil is introduced. The hydrogen needed in the hydrogenation step is produced internally at Preem in a process giving also other energy rich product streams. The environmental impacts are allocated between the hydrogen and different byproducts based on energy contents of the streams out from the hydrogen production unit. After the hydrogenation, the product is a tall diesel that directly is blended into conventional diesel oil.

If the tall oil is not sold from the pulp mill, it could be used as fuel within the mill. When sold, the pulp mill loses some bioenergy. In the case of system expansion it can be argued that it should be included that the pulp mill will need other fuels to cover the balance between the tall oil and the tall pitch (that is sent back). Here, we have assumed heavy fuel oil being used, adding the impacts from fuel oil production and the fossil carbon dioxide from its incineration.

7. DME from black liquor

DME is produced from methanol which is synthesized from carbon monoxide and hydrogen. This synthesis gas come from gasification of black liquor. There is an advantage of gasifying black liquor compared to wood since it is locally available in large quantities, it is pump able and a specific fuel can be produced. Little more than half of the energy from the wood that is fed to a chemical pulp plant is found in the black liquor. This means that the gasifier is fairly large and this is important for the economy of the plant. Furthermore an industrial infrastructure is already on the site since the pulp is already in production. One difficult part of gasifying solids is the addition to the solid to the gasifier in a practical way, especially if high pressure is wanted for the synthesis and cleaning steps as in this case. DME is a special fuel that does not need any further upgrading to be used in a diesel. The diesel engine has to be adapted for DME and a new distribution has to be built. In a modern pulp industry it is possible to produce electricity of the excess heat that is available that has done energy savings and is producing electricity for sale. This reduces the potential for gasification. To change system in a plant it should be an old not energy optimized plant or a complete new plant were the selection of gasification instead of the soda recovery boiler is more open. The part of energy not saved in the plant has to be supplied by new sources and a boiler for doing this have to be built.

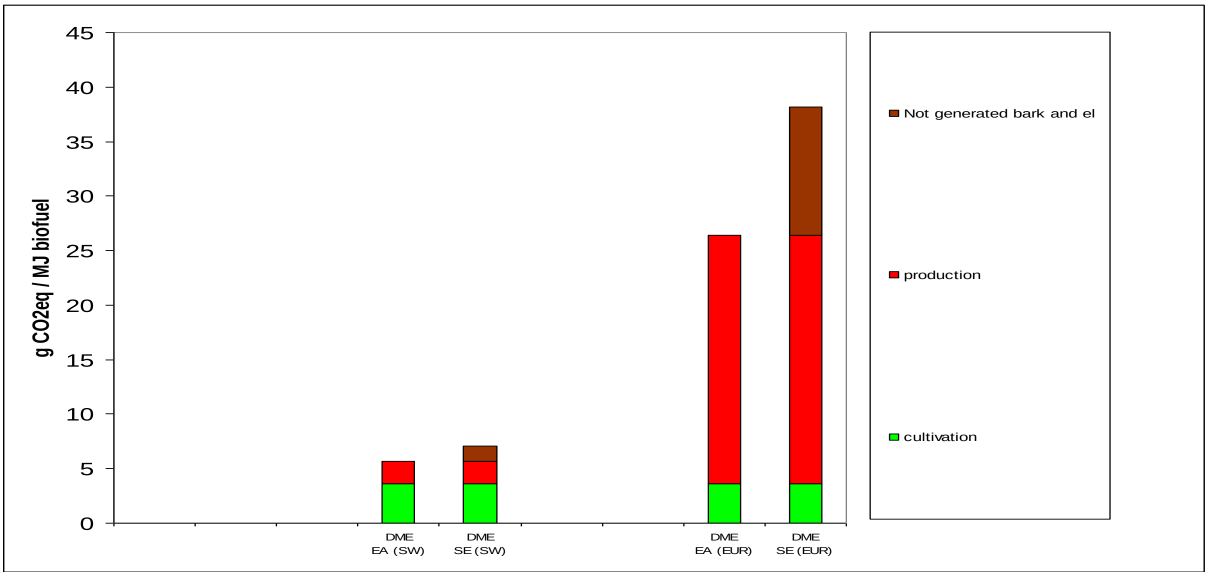
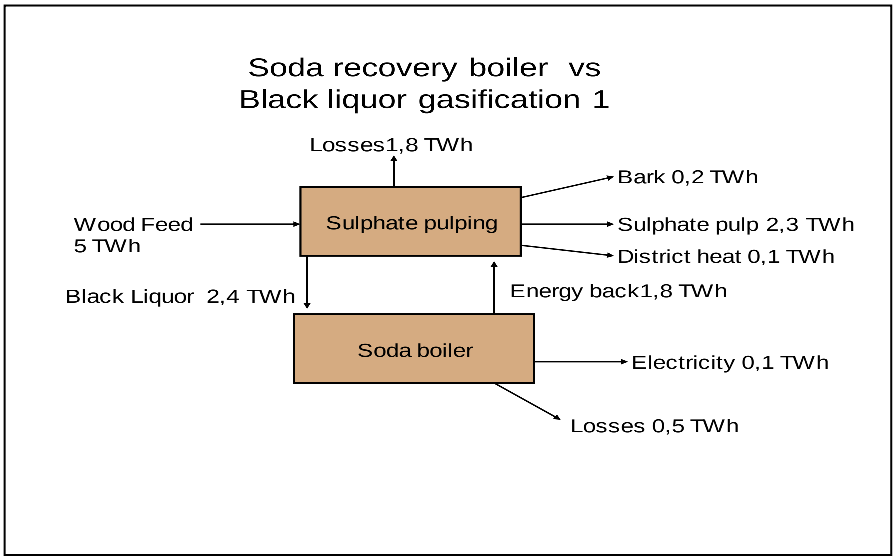


Figure 4 Simple block diagrams for the DME process from a pulp mills perspective. EA=energy allocation, SE=system expansion



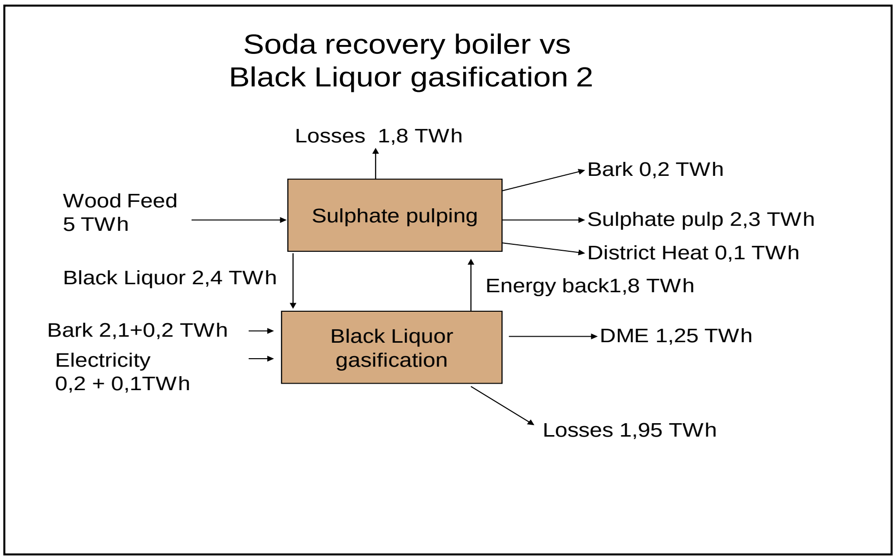


Figure 5 Simple overview of main activities in the product system for DME from a pulp mills perspective.
The material flows in the figures are taken from Värö pulp mill.

8. Results for climate change - GWP

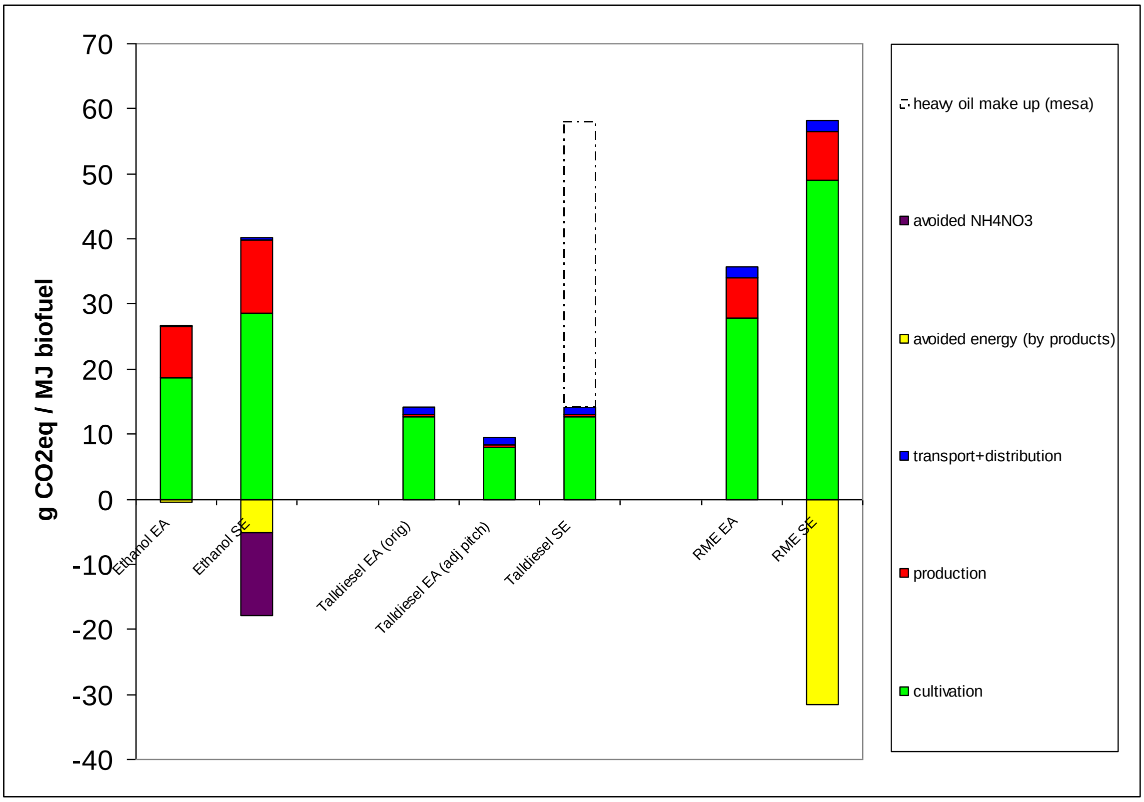


Figure 6. Results for Ethanol, tall diesel and RME. EA=energy allocation, SE=system expansion.

The net results for Ethanol become slightly larger using energy allocation, 26,2 g/MJ, compared to system expansion, net balance 22,4 g/MJ. The difference is about ±20%, less than the difference that could be generated by switching to the data set for wheat cultivation used in the Well-to-Wheel study [3] describing Swedish wheat instead of the Baltic region JRC data now used for the wheat case. The results also draw from different sources. Roughly you can say that the energy allocation lowers total emissions for ethanol through seeing the biogas and solid biofuel co-produced as responsible for some of the upstream emissions from the agricultural part, whereas the system expansion to the largest part gives credit for avoided fertilizer production that gives a lower total balance.

The net results for RME is larger using energy allocation, 35,6 g/MJ, compared to system expansion, net balance 26,5 g/MJ. The difference is about ±30%, about the same magnitude as differences that might arise from what figure of rape yield that is used (data given in [3]). We get the differences in results for similar reasons as in the ethanol case. The rape meal is used as fodder and glycerol. The upstream processes avoided, e.g. agriculture for fodder production including fertilizers, give a larger credit compared to what of the rape oil production that is allocated to the fodder in the energy allocation case.

The total result for Pine diesel is in the energy allocation case smaller compared to the ethanol and the RME production, largely because of having a raw material that is a co product. The main reason for the forestry is for pulp production. However it should be noted that the tall oil is available in limited quantities. It is not reasonable to believe that we would start forestry specifically for tall oil generation, and it is thus limited to how much pulp we need for other purposes. Another reason is that forestry also includes somewhat less management operations and fertilizer use compared to agriculture.

Regarding system expansion the results are very dependent on the calculation method. Here the crucial question is not if we should divide impact in one way or the other, but how to think of the upstream activities. If the tall oil is used for the tall diesel production, it can not at the same time be used for energy purposes in the pulp mill. If we assume that the pulp mill will use heavy fuel oil for making up for the lost energy in the sold tall oil, and we include this in the calculations, the impact from tall oil increases dramatically (as indicated in the dotted bar in Figure 6). However, perhaps the pulp mill would use natural gas or a biofuel to make up for the sold tall oil – that would make the results and the dotted bar less dramatic. About 95% of the dotted bar is made up from the fossil carbon dioxide from the incineration of the fuel oil.

9. Change in land use

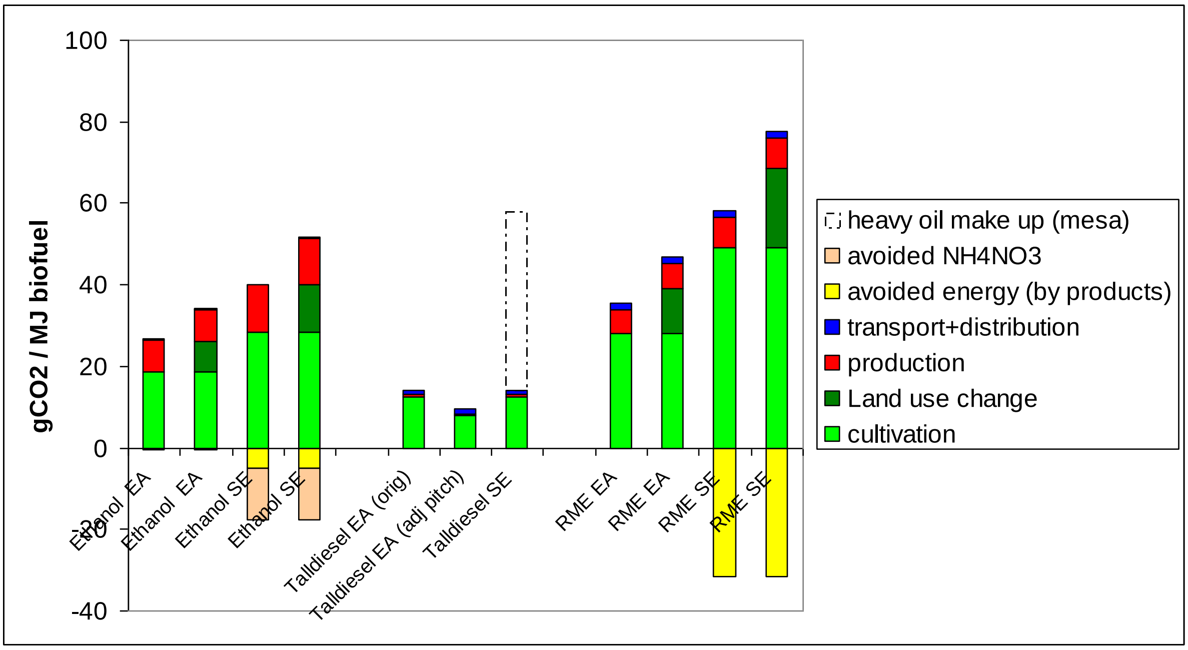


Figure 7. Results showing changes in impacts if land use change from grassland into agricultural land. EA=energy allocation, SE=system expansion

In the tall diesel study, land use change is not discussed. In the wheat ethanol study impacts from land use change due to the biofuel production is discussed but in the end not furthered considered. In the RME study land use change is discussed in a sensitivity analysis.

If the rape seed is considered to originate from new areas farmed that earlier was grass land, and using estimates for emissions due to land use change, the total emissions from the agricultural phase could potentially increase with 50% or more. If more land is needed it is logical to assume that part of this land was earlier grass land. Since the agricultural phase is a considerable part of total emissions for the RME production this could increase the net end impact from the fuel production with 40-100% depending on methodological regime.

The example is for the agricultural production of rape seed for REM, but should be roughly applicable also to the agricultural production of wheat for ethanol. Note that this whole discussion is only applicable if land use change will actually occur.

Figure 6 indicates what would happen if land use change from grass land into farmland would occur for ethanol from wheat and RME from rape seed, assuming an 40% increase in emissions from farming. Land use change into forested area is not expected to result in emissions of this kind, thus there is no change in the results for the Tall diesel.

10. Area use

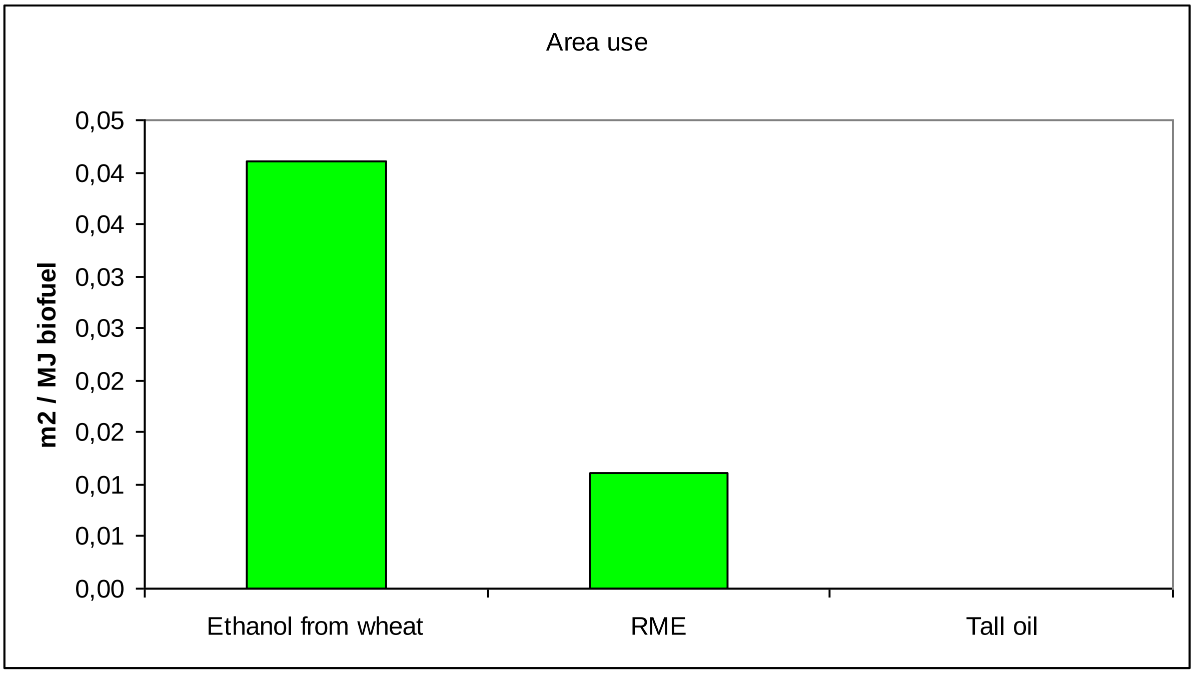


Figure 8. Estimated land use per MJ of produced biofuel.

Using yields given in the main RME study for rape seed (3,2 ton/ha*yr) and wheat (6,4 ton/ha*yr) the area need per MJ of biofuel can be calculated when using the energy calculation methodology to 0,01 m^2*yr /MJ for RME and 0,04 m^2*yr/MJ for wheat ethanol. Energy allocation has been applied for byproducts in each production chain.

For the tall diesel the case is not as straightforward, since we generally assume that the reason for the forestry connected to the pulp mill is to produce pulp. If so, the area use for tall oil is zero. This is the result indicated in Figure 7. However, if we assume that we have the forestry equally for the pulp and the tall oil and use energy allocation which in this case is not logical. An annual growth in Swedish forests of about 120 Mm^3 and a forested area of 22 Mha we arrive at a considerable larger figure for the tall diesel compared to the agricultural products 0,6 m^2*yr/MJ. Depending on the way of thinking we thus arrive either at a very small value or a very large value. The area use will not increase since this amount of tall oil comes from the pulp processing.

11. Comments on nitrous oxides from soil microbial activities

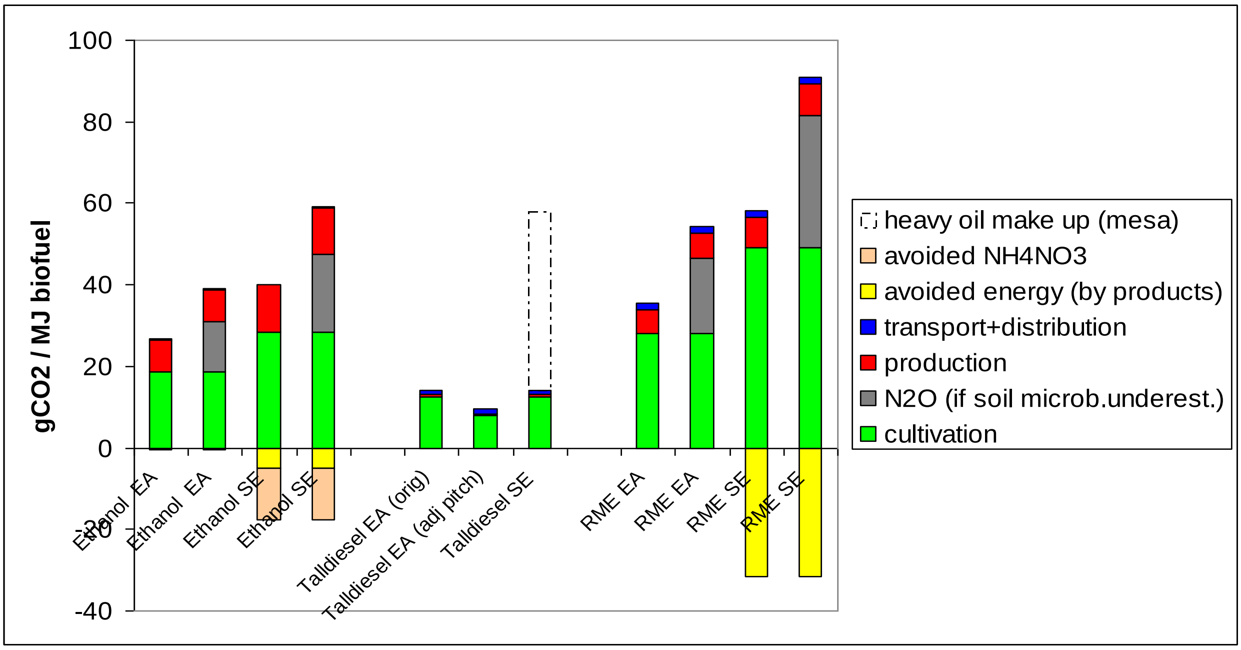


Figure 9. Changes in results if nitrous oxides (N2O) from soil microbial activates is underestimated with a factor three.

Soil microbial processes transfer some of the nitrogen applied with fertilizers to nitrous oxides, a potent green house gas. Data for such emissions are included in the RME study and probably in the ethanol study (the magnitude of the impact from farming indicates that this probably is the case). The nitrous oxide from soil microbial activity is for the RME case based on an IPCC estimation method. Regarding agricultural production of rape seed, soil microbial emissions seem to make up around a quarter to half of the total impact of gases influencing climate change in different studies using the IPCC estimation method. If the indications of an underestimate in nitrous oxide from soil microbial activities with a factor three are correct, the agricultural production phase impact regarding climate change might increase with half or more.

Note that this is only applicable if the indications of an underestimate are correct and where nitrogen fertilizers are applied to land in the cultivation phase.

12. General Discussion / Conclusion

The purpose with this project was not to compare the different alternatives with each other. But never the less it is interesting to see the large difference of taking the raw materials from the forest instead of farming. This can also be expressed as the second generation of methods is by far better than the first generation of methods studies in this report. We have not assumed any fertilization in the forest to improve yields. If this is done it will negatively affect the alternatives taking forests as primary feed material.

There is a large need of replacing crude oil therefore it is necessary to use many different method since the quantities of petroleum products that have to be phased out is so large.

The use of the Renewable Energy Directive for method with energy allocation compared to the traditional system expansion in the LCA did not give a big difference in the four studied alternatives. It is much easier to follow different activities with the directives method of energy allocation. While system expansion leads to more discussions and is therefore more difficult.

One huge advantage with system expansion though is that this is in a higher degree leading to future environmental improvements.

References

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