Environmental impacts of ethanol from a Norwegian wood-based biorefinery

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Abstract Borregaard owns and operates a highly advanced biorefinery in Sarpsborg/Norway, and has a long history in producing products from renewable sources. To be able to improve and document the products environmentally, LCA's and EPD's of Borregaard's main products have been made. This paper describes the results and conclusions from the analysis of ethanol. A complex process model has been made, as the processes are closely integrated and the products are mutually dependent on each other due to use of co-products and energy in the internal loops. The results for several environmental impact indicators are shown. The results show that reducing the energy use at Borregaard will to a large extent affect all the impact categories in a positive way, with the eutrophication potential being the only exception. Generation and use of energy are the sources for most of the burdens along the value chain of ethanol from the Borregaard biorefinery.

1 Introduction

Borregaard owns and operates a highly advanced biorefinery in Sarpsborg, Norway, and has a long history in producing biochemicals, biomaterials and bioethanol from renewable sources. Bioethanol production started at Borregaard in 1938 and the hemicellulose from Scandinavian spruce has been the raw material since the start.

In total, Borregaard consumes approximately 340,000 tonne of DM timber annually. This is transformed to cellulose (150.000 tonne DM), ethanol 96% (8,000 tonne), ethanol 99% (5,000 tonne), lignin products (150,000 tonne DM) and vanillin (1,300 tonne DM) in addition to sodium hypochlorite, hydrochloric acid, chlorine and several pharmaceutical products.

To be able to improve the products environmentally and to document the environmental properties, LCA's and EPD's of Borregaard's main products cellulose, liquid lignin, lignin powder, ethanol 96%, ethanol 99% and vanillin have been made. This paper describes the results and conclusions from the analysis of ethanol from Borregaard, which is used both in the production of biofuel (ethanol 96% and ethanol 99%) as well as pharmaceuticals and in chemical and technical applications (ethanol 99%).

2 Methodology

2.1 Goal and functional unit

The study is carried out using life cycle assessment (LCA) methodology based on the ISO-standards 14044/48 [1]. Life cycle assessment of a product is defined as systematically mapping and evaluation of environmental and resource impacts throughout the entire life cycle of the product, from ”cradle to grave”. The analysis is based on a product system, and considers environmental and resource impacts in relation to a defined functional unit, describing the performance of the product according to particular user needs.

The goal has been to calculate the environmental impacts for the ethanols produced at the Borregaard factories in Sarpsborg, Norway. The functional unit is 1 m3 ethanol. The analysis is performed on a 'dry basis', meaning that the analysis is done per tonne dry matter (DM) of the products. For ethanol this means that the environmental impacts are distributed only on the amount of ethanol in the product (water contents are 4% and 0,1%). The analysis is based on modelling of the physical, isolated processing plants at the biorefinery. A complex process model has been made to perform the analysis; internally at Borregaard's premises there are many factories and process plants, and the raw materials are processed in several installations before they end up as finalised products. All products are based on the same raw materials (timber and wood chips) and are mutually dependent on each other due to use of internal co-products and energy in the internal loops. The processes are hence very closely integrated.

2.2 Allocation

The study has as far as possible avoided allocation by analysing and modelling the processes of the biorefinery on a detailed level. Outlet streams from one process plant are used as important raw materials in other process plants, hence no such intermediate product is excluded from allocation. Several of the allocations are done on products that have no marked value, making economic allocation unsuitable. Based on this, mass allocation has been chosen for distribution of environmental loads internally at the biorefinery. In process plants with hot water as out flow, and where the hot water is exploited in other processes, the energy content is calculated into mass through the heat value (LHV) for biological dry matter. In this way mass allocation of the environmental loads of the different products may be carried out. This will give the same results as by energy allocation between hot water and mass flows in the form of dry matter. Table 1 shows heat values (LHV) and densities used in the allocation.

Tab.1: Applied heat values and densities

	Heat value (LHV)		Density		Reference/ comment
Biological dry matter	6.8	GJ/fm3	0.4	tonnes/fm3	[2]
	17	GJ/tonnes	-	-	Calculated
	4.7	MWh/tonnes	-	-	Calculated
Ethanol	29.7	MJ/kg	0.789	kg/l	[3]

2.3 System boundaries

The analysis is a “cradle to gate” analysis, meaning that all upstream processes and processes taking place at the biorefinery are included. As the analysis stops “at the gate”, the use of the products is not included. Anyhow, in order to easily develop EPDs on basis of this analysis, 100 km transport of finalised product to the customer, weighted by transport means, is comprised in correspondence with requirements in PCR for chemical products [4].

The analysis includes the infrastructure, such as buildings, tanks, containers and fundaments of the process plants at the biorefinery, and process plants for production of raw materials and chemicals. The infrastructure mass is distributed on the total produced mass during the life span of the installations (40 years).

2.4 Dataset and conditions

The dataset is originally from 2007, updated in 2010 with data regarding the steam producing system and the biological effluent plant. Consumption data are based on Borregaard figures, with basis in material and energy flows through the process plants. Data for emissions to air and water are the same numbers as Borregaard reports to the Norwegian Climate and pollution agency (KLIF) and these are all updated to 2010 numbers. Production of steam in the boiler house, the bark combustion plant, the waste combustion plants and the biofuel plant and the consumption of energy carriers in each of these plants are solely based on numbers from 2010. Emissions from production of the main raw materials timber and wood chips in addition to three chemicals are based on specific data. Data for the other upstream production processes of chemicals are given by databases. This is also applicable for transport, but specific data for transport type and distances are utilised. General data (from databases) has been used for emissions from combustion processes. For 5 of the 39 chemicals there existed no data in the LCA database. For these chemicals production data for other chemicals are used by careful judgement. It is assumed that waste, waste oil and biogas are without environmental impacts as they are waste products. Transport and combustion of these do on the other hand lead to emissions that are allocated to Borregaard’s products.

Borregaard has both production of hydro power and access to rights of ownership to waterfalls for hydro power. However, as Borregaard both produces, uses, purchases and sells power, and part of this trade goes via the power exchange Nord Pool, the Nordel-mix (which is the best approximation of what is traded on Nord Pool) is used as the electricity model in the analysis.

2.5 Environmental impact indicators

The environmental impact indicators global warming (GWP), acidification, eutrophication, photochemical oxidation, ozone layer depletion, cumulative energy demand and waste have been used in the analysis. The characterisation method for the different environmental impact categories is based on the methods given in Table 2. The SimaPro 7.2.4 software [5] has been used together with the Ecoinvent 2.2 database [6] in order to carry out the analyses.

Tab.2: Impact assessment methods used in this study

Environmental impact category	Impact assessment method	Unit
Global warming potential (GWP)	IPPC 2007 GWP 100a, V1.02.	kg CO2-eqv.
Acidification potential	CML 2 baseline 2000, V2.05.	kg SO2-eqv.
Eutrophication potential	CML 2 baseline 2000, V2.05.	kg PO4-3-eqv.
Photochemical ozone creation potential (POCP)	CML 2 baseline 2000, V2.05.	kg C2H4-eqv.
Ozone depletion potential	CML 2 baseline 2000, V2.05.	kg CFC-11-eqv.
Cumulative energy demand, several categories (CED)	CML 1992 V2.06 and Cumulative Energy Demand V1.07 by Ecoinvent.	MJ LHV
Waste	EDIP/UMIP 97 V2.03.	kg waste

3 Findings

3.1 Global warming potential

Figure 1 shows the contribution to the global warming potential in kg CO2-equivalents per m3 ethanol. The figure shows GWP split into the different raw materials, the infrastructure at Borregaard, the different processes at Borregaard and transportation to customer. More details are shown in the LCA network (Figure 2), where the relative contribution from different processes and some of the loops are shown.

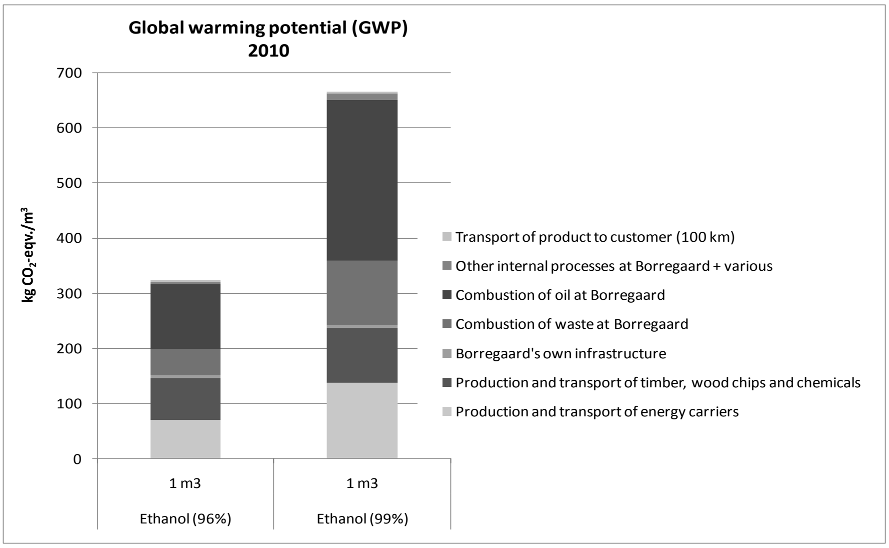

Fig.1: **The global warming potential from craddle to customer for ethanols from Borregaard.**

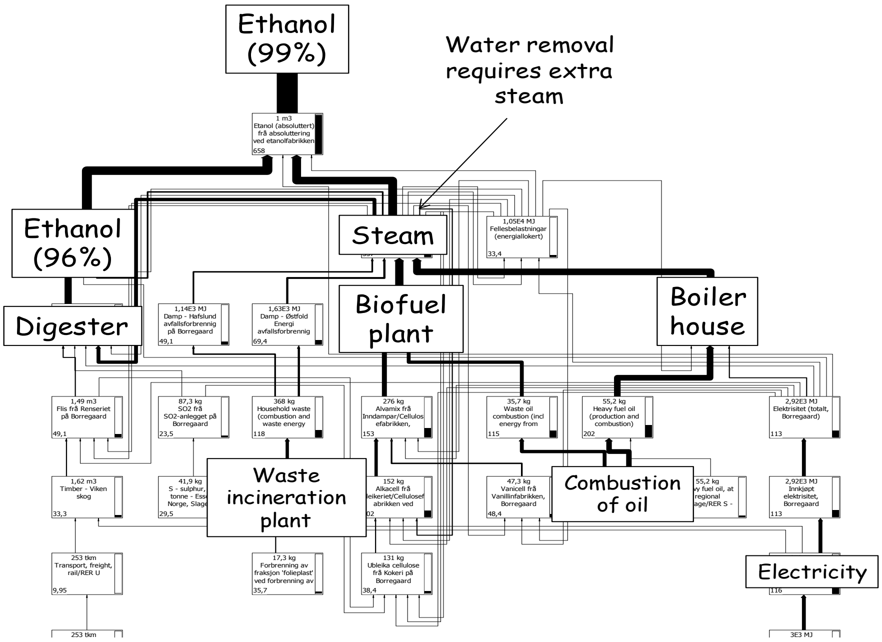

Fig.2: **The global warming potential from cradle to customer, shown as an LCA network, for ethanol 99% from Borregaard (kg CO2-eqv./m3). 3.0 % cut off is applied to make the figure readable.**

Oil combustion contributes the most (36% and 44%) to the global warming potential for ethanol 96% and ethanol 99%. The next largest contributor is production and transport of energy carriers (22% and 21%), where production of electricity has the largest impact. The succeding contributor is production and transport of timber, wood chips and chemicals (24% and 15%). Waste combustion represents 15% and 18% of the global warming potential while transportation to customer and production/waste handling of the infrastructure at Borregaard represent both approximately 1%.

Ethanol 99 % is produced by ethanol 96 %, and the only difference between the products is that the water has been removed in ethanol 99 %. For the water removal, energy as electricity and steam is used.

For comparison with emissions from a petrol driven car, an average fuel consumption of between 0,09-0,11 l/km (ethanol 96%) and 0,06-0,07 l/km (petrol) are used [7]. These fuel consumption numbers are based on a common, ‘virtual’ vehichle, representing a typical European compact size 5-seater sedan, comparable to e.g. a VW Golf. Using a fuel consumption of 0,10 l/km, the result 320 g CO2-eqv./l for ethanol 96% and assuming negligible GWP from combustion, the GWP for production and combustion of fuel in a bioethanol driven car would be approximately 32 g CO2-eqv./km. The corresponding number for a petrol driven car would be approximately 240 g CO2-eqv./km [8].

3.2 Results for the other environmental indicators

The total results for all the analysed environmental impact categories are shown in table 2. In figure 3 the life cycle phases’ relative burden for five of the environmental impact categories are shown.

Tab.2: Environmental burdens from cradle to customer* for Borregaard’s products

Environmental impact category	Unit	Ethanol (96 %) 1 m3	Ethanol (99 %) 1 m3
Global warming potential (GWP)	kg CO2-eqv.	320	670
Acidification potential	kg SO2-eqv.	4.5	7.2
Eutrophication potential	kg PO4-3-eqv.	2.2	2.7
Photochemical ozone creation potential (POCP)	kg C2H4-eqv.	0.3	0.5
Ozone depletion potential	kg CFC-11-eqv.	3E-05	5E-05
Cumulative energy demand (CED)	MJ LHV	8700	18000

Waste#	kg waste	410	790

Solid and non-radioactive.

* On dry basis. This means that the burdens are not allocated the water content of the product.

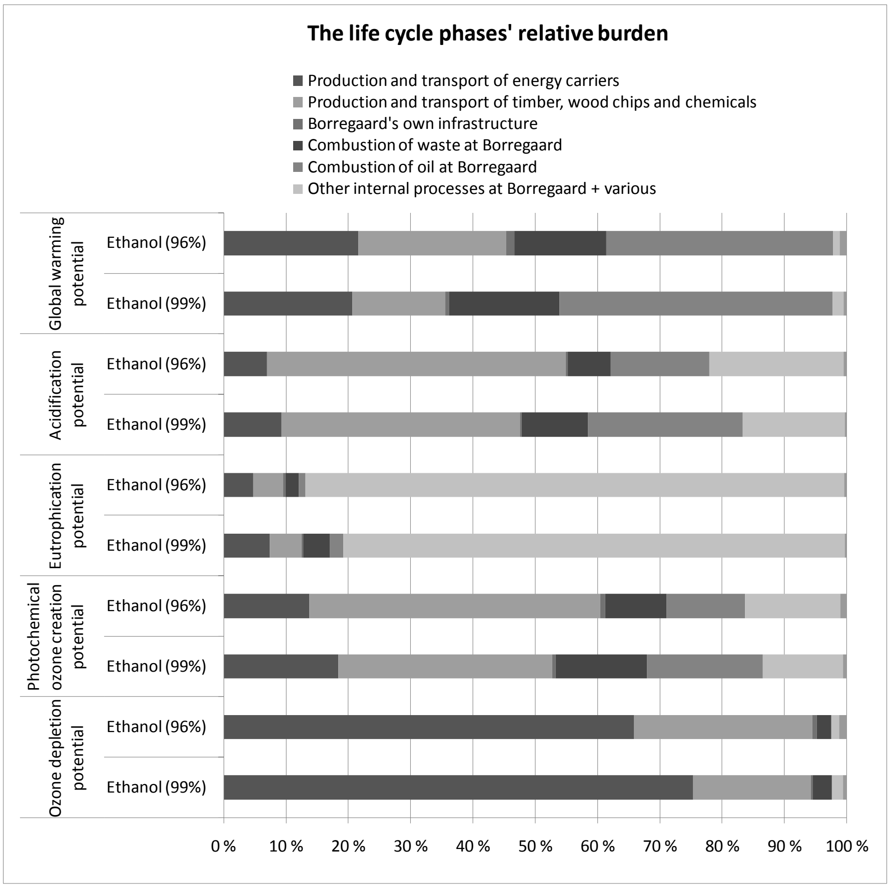

Fig.3: The life cycle phases’ relative burden.

For the impact categories acidification and photochemical ozone creation potential, the life cycle phases' relative burden is quite similar to those for global warming potential.

When it comes to eutrophication, ’Other internal processes at Borregaard + various’ dominates (86% and 80% of the impact). This is due to COD emissions from the different factories at Borregaard. It is the bleaching plant that contributes the most, followed by the ethanol plant and the biological effluent plant, then comes the digester and the lignin plant.

Regarding the ODP, production and transport of energy carriers dominate (66% - 75%), followed by production and transport of timber, wood chips and chemicals (29% - 19%). These contributions are due to emissions of methane from offshore activities connected to production of fossil energy.

4 Discussion

Reducing the energy use at Borregaard will to a large extent affect all the impact categories in a positive way, with the eutrophication potential being the only exception as an impact category which is not as significantly correlated to energy use. A further transition to more use of renewable energy (bio energy, energy from waste, electricity with guaranty of origin) and hence reduced use of fossil energy, will also reduce the global warming potential and the ozone depletion potential, but the results for the other impact categories are challenging to estimate without performing analyses of such scenarios.

Borregaard also emits compounds not included in this analysis, because they do not affect the selected impact categories. These compounds are potentially environmentally relevant, for instance related to toxicity.

5 Conclusions

The results show that the global warming potential is 320 kg CO2-eqv./m3 for ethanol 96% and 670 kg CO2-eqv./m3 for ethanol 99%. The result for ethanol 96% corresponds to approximately 32 g CO2-eqv./km for production and combustion of fuel in a bioethanol driven car.

As for GWP, ethanol 99% has a higher burden than ethanol 96% for all the other environmental impacts analysed. This is due to higher use of electricity and steam for water removal.

Which life cycle phase is most significant varies depending on what impact category is in focus. Energy production and/or use is important for most of the environmental impact categories, but the eutrophication potential stands out because other internal processes than combustion (mainly emissions of COD) contributes with as much as 80% - 86% of the total burden.

Transport to customer is not significant for any of the environmental impacts analysed. Except for the waste indicator, this applies also for the biorefinery's infrastructure.

Generation and use of energy are the sources for most of the burdens along the value chain of ethanol from the Borregaard biorefinery.

6 Further work

Borregaard is now increasing the waste incineration capacity and extending the anaerobic biological effluent plant, which will lead to increased production of biogas. These measures will both affect the future burdens of ethanol from Borregard, most probably in a positive way.

7 References

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