

REVIEWING THE ENVIRONMENTAL IMPLICATIONS OF INCREASED BIOFUEL CONSUMPTION IN SWEDEN

Summary Report from an f3 project

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PREFACE

This report is the result of a project within the Swedish Knowledge Centre for Renewable Transportation Fuels (f3). f3 is a networking organization, which focuses on development of environmentally, economically and socially sustainable renewable fuels, and

- Provides a broad, scientifically based and trustworthy source of knowledge for industry, governments and public authorities,
- Carries through system oriented research related to the entire renewable fuels value chain,
- Acts as national platform stimulating interaction nationally and internationally.

f3 partners include Sweden's most active universities and research institutes within the field, as well as a broad range of industry companies with high relevance. f3 has no political agenda and does not conduct lobbying activities for specific fuels or systems, nor for the f3 partners' respective areas of interest.

The f3 centre is financed jointly by the centre partners, the Swedish Energy Agency and the region of Västra Götaland. f3 also receives funding from Vinnova (Sweden's innovation agency) as a Swedish advocacy platform towards Horizon 2020. Chalmers Industriteknik (CIT) functions as the host of the f3 organization (see www.f3centre.se).

This report is an extended summary of the project *Accumulated impacts from increased biofuel consumption in Sweden*. The project has included the development of a database of Imports-Consumption of Fuels and Raw Materials, and an LCA Model for Inputs-Consumption of Biofuels in Sweden. It has been presented at the 4th International Exergy, LCA and Sustainability Workshop and Symposium, Nisyros, Greece (SETAC Europe LCA Case Study Symposium), 2015, and at the Advanced Biofuel Symposium, Montreal, Canada, 2015.

Further, the project is also documented within a master thesis and a manuscript submitted for publication in *Applied Energy*:

- Larsson, M. *Environmental assessments and Swedish consumption of biofuels. Review of Swedish biofuel research and aggregated life cycle assessment of Swedish biofuel consumption 2000-2013*. Master of Science Thesis, KTH Royal Institute of Technology. Stockholm 2015.
- Martin, M. et al. (Submitted) *Increased Biofuel Consumption and Trade in Sweden: Reviewing the Environment and Political Implications* Manuscript submitted to *Applied Energy*, Special Issue "Sustainable biofuel production from biomass feedstocks" September 2016.

Additionally, work and knowledge from the project has had important synergies effects with the f3 project *Environmental and Socio-Economic Benefits of Swedish Biofuels*, for quantitative assessments and data collection. This project is led by Lund University and will deliver results in 2016.

This report should be cited as:

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SUMMARY

Through ambitious targets and goals, Sweden has surpassed targets set by the EU for biofuel consumption and is a European leader in the consumption of biofuels. Correspondingly, the use of biofuels in Sweden has increased rapidly since 2000. In 2014 biofuels corresponded to roughly 12% of transportation fuels.

In the context of identifying the environmental implications of Swedish biofuel consumption, this project reviewed the origins of fuels, and raw materials used to produce the fuels from 2000-2014. This was done to identify and provide a comprehensive review of environmental implications that biofuel consumption (including imports and domestic production) of fuels have both in Sweden and abroad using life cycle assessment.

The results suggest that the increase in biofuel consumption has been met largely in part through the introduction and expansion of HVO, an increasing biogas production and consumption market and the imports of raw materials and fuels from Europe and other nations abroad. The consumption of both ethanol and biodiesel stagnated during the same period. A large share of the biofuels, and raw materials used to produce the fuels, are imported from regions outside Sweden; primarily Europe.

The environmental assessments illustrate that while GHG emissions may have been reduced in Sweden by the use of biofuels, the origin of the emissions has shifted from Sweden to other countries abroad; due largely in part to an increased use of biofuels and raw materials from abroad. Imports have been shown to have important local environmental implications, leading to increases of acidification and eutrophication potential and ecotoxicity created abroad. Domestic biofuels were also shown to have superior environmental performance. Nonetheless, imports of fuels from abroad have continued to increase, while in recent years, exports of domestically produced biofuels have also increased, thus calling into question the promotion of domestic production.

This study thus provides a comprehensive review of the implications of biofuel trade for the Swedish market. The results illustrate that although policy has been designed to promote sustainable transportation fuels, the implications on regions exporting fuels and raw materials for Swedish consumption in addition to the generation goals set by the Swedish Parliament, should be reviewed in order to avoid problem shifting and promote domestic production.

SAMMANFATTNING

Konsumtionen av biodrivmedel i Sverige har stadig ökat sedan år 2000. Under 2014 nådde biodrivmedelskonsumtionen 14 % av den totala drivmedelskonsumtionen, med vilket Sverige nu är ledande i EU för biodrivmedelskonsumtion. Det överträffar med god marginal EUs mål för Sverige, och detta har uppnåtts genom högt uppsatta mål och ambitiös styrning.

I detta projekt kartläggs de miljömässiga följderna av denna biodrivmedelskonsumtion i ett livscykelperspektiv genom att kartlägga ursprunget av bränslens råmaterial och produktion över åren 2000-2014. Syftet med projektet har varit erhålla en utförlig överblick av de miljöeffekterna i ett livscykelperspektiv av denna snabba ökning av biodrivmedelskonsumtionen (både med avseende på inhemsk och utländsk produktion).

Resultaten visar på att konsumtionsökningen av biobränslen i hög grad har mötts bl.a. genom introduktionen och expansionen av HVO, av en ökad produktion och växande marknad för biogas, samt genom import av råvaror och bränslen från Europa och andra länder. Under samma period skedde en stagnation av såväl etanol- som biodieselskonsumtionen. En stor andel av biobränslen, liksom råvaror för bränsleproduktion, importeras från regioner utanför Sverige, främst Europa.

Miljöbedömningar visar att samtidigt som utsläppen av växthusgaser har minskat i Sverige till följd av biobränsleanvändningen, har utsläppens ursprung flyttats från Sverige till andra länder. Detta beror till stor del på den ökade användningen av råvaror och biobränslen från utlandet. Det har visat sig att importen kan ge väsentliga lokala effekter, till exempel kan de öka på den försurnings- och övergödningspotential och ekotoxicitet som skapats utomlands. Inhemska biobränslen har också visat sig ha överlägsen miljöprestanda. Icke desto mindre har importen av bränslen från utlandet fortsatt att öka, likaså exporten av inhemskt producerade biobränslen de senaste åren. Detta gör att främjandet av den inhemska produktionen kan ifrågasättas.

Sammanfattningsvis presenterar denna studie en omfattande översyn av konsekvenserna från biodrivmedelshandeln på den svenska marknaden. Resultaten visar att policyn för att främja hållbara bränslen medför implikationer i de regioner som exporterar bränslen och råmaterial till svensk konsumtion. Detta går emot de svenska miljömålen, fastslagna av riksdagen. Därför behöver hållbarhetspolicyn se över i syfte att undvika att miljöproblem ökar i andra länder.

1. INTRODUCTION

1.1 BACKGROUND

In response to an increased dependence on fossil fuels, and to reduce the effects of climate change, nations worldwide have increased their consumption of biofuels in the transportation fleet through policies, reduced taxes, blending obligations and targets. In the European Union, member states are obligated to meet mandatory targets of 10% renewable energy in the transport sector before 2020, as stipulated by the European Commission (2009). Sweden has emerged as a leader in biofuel consumption in the European Union (EurObserv'ER, 2014; Eurostat, 2015), with reported shares of over 12% and 15% biofuels in the transportation sector, respectively.

In order to promote biofuels, the Swedish science-policy framework has promoted biofuels as a carbon neutral option since the early stages of their use; (Eklöf 2011). Nonetheless, a number of recent studies suggest that a focus on carbon can lead to sub-optimizations and increased local impacts (Luo, van der Voet et al. 2009, Laurent, Olsen et al. 2012, Martin, Lazarevic et al. 2015). As Sweden has seen increased imports of fuels to meet demand, it is important to highlight the impacts that production abroad may have for local impacts versus those that are global; for which the national generational goal and National Environmental Objectives have been developed to address (Naturvårdsverket 2013).

1.2 AIM

The overall aim of this project was to review the environmental implications of biofuel consumption in Sweden from 2000-2014 in order to understand and assess the effects consumption may have not only in Sweden, but also abroad from a more comprehensive base of environmental impact categories. Specifically, the following objectives are addressed:

- Review the origin of fuels and raw materials used to produce fuels consumed in Sweden
- Highlight the origin of emissions produced from the production of biofuels and raw materials imported to Sweden for biofuel consumption
- Review the emissions annually and accumulated over the period 2000-2014

The information discussions have the objective to provide knowledge on the implications of policy on trade and biofuel development, which ultimately aim to influence biofuel policy and better decision making for future biofuel production and consumption.

2. METHOD

Five main steps were included to review the origins of fuels and raw materials and to assess the environmental implications of Swedish biofuel consumption. These included:

1. Data collection for biofuel consumption in Sweden 2000-2014,
2. Identifying the origin of biofuel imports,
3. Identifying the origin of raw materials used to produce the biofuels in each country of origin,
4. Collecting life cycle inventory data collection for production processes and raw materials and
5. Assessing the environmental implications from a life cycle perspective.

2.1 PRODUCTION LOCATION

Consumption figures and production location for biofuels consumed in Sweden are provided primarily from reports from the Swedish Energy Agency (SEA) (Energimyndigheten 2014, Energimyndigheten 2015). Prior to 2011, data for consumption and origins of fuels was limited. Information was provided from reports on the energy use in the transport sector from the Swedish Energy Agency (2008, Energimyndigheten 2015) and compared with production statistics for Swedish biofuels during the same period (Energimyndigheten 2012, Energimyndigheten 2013, Energimyndigheten 2014, Energimyndigheten 2015). Thereafter, production amounts for biofuels from Sweden and abroad were outlined and validated with experts and industry representatives.

2.2 RAW MATERIAL ORIGIN

From SEA reports (Energimyndigheten 2013, Energimyndigheten 2014, Energimyndigheten 2015) the share of different raw materials were identified for the years 2011-2014. For 2000-2010, again a triangulation of data sources and expert validation was used. Based on the information provided, the production and raw material regions were split into Sweden (SE), Europe excluding Sweden (EU), and the Rest of World (ROW).

2.3 LIFE CYCLE ASSESSMENT

Life cycle inventory (LCI) data for production processes of the biofuels and raw materials was provided primarily from Ecoinvent v. 3.1 (Ecoinvent 2014) and databases for Swedish biofuel production, provided in deliverables from the f3 project Well-to-wheel LCI data for fossil and renewable fuels on the Swedish market. (Hallberg et al. 2013) in order to allow for comprehensive reviews of environmental impacts.

The life cycle assessments for the fuels and time period 2000-2014 were conducted using the program Gabi ts (Thinkstep 2015) and applying the ILCD recommended characterization factors (JRC 2010). The functional unit of the assessments were set to the annual consumption of fuels in Sweden in order to illustrate the change in environmental impacts over time. The assessments were conducted using well-to-tank, i.e. cradle-to-gate, system boundaries.

3. RESULTS

The project resulted in a review of the consumption, origins and raw materials used to produce the biofuels consumed in Sweden. This was followed by a review of the environmental impacts associated with the consumption of the biofuels in Sweden.

3.1 CONSUMPTION, PRODUCTION LOCATION AND RAW MATERIAL ORIGINS

Figures 1 and 2 provide a review of the fuels consumed in Sweden, and their production origins. The results illustrate a large increase in HVO production in recent years. Biogas has also seen a steady increase, while the consumption of biodiesel and ethanol have saturated.

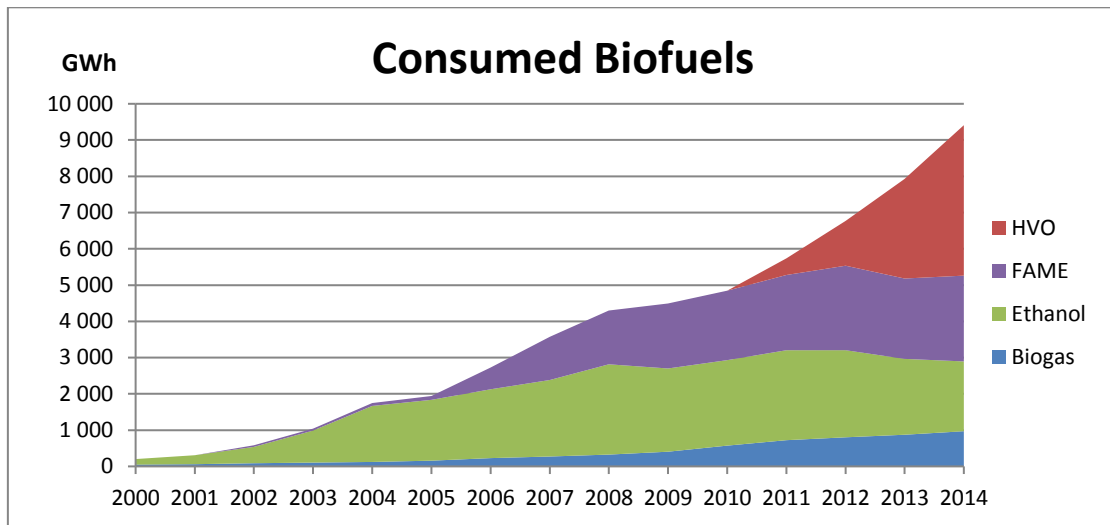


Figure 1. Consumption of biofuels in Sweden for transportation 2000-2014 (measured in GWh).

Figure 2 illustrates that a large share of biofuels are imported to Sweden from abroad, with large increases in European produced biofuels in recent years.

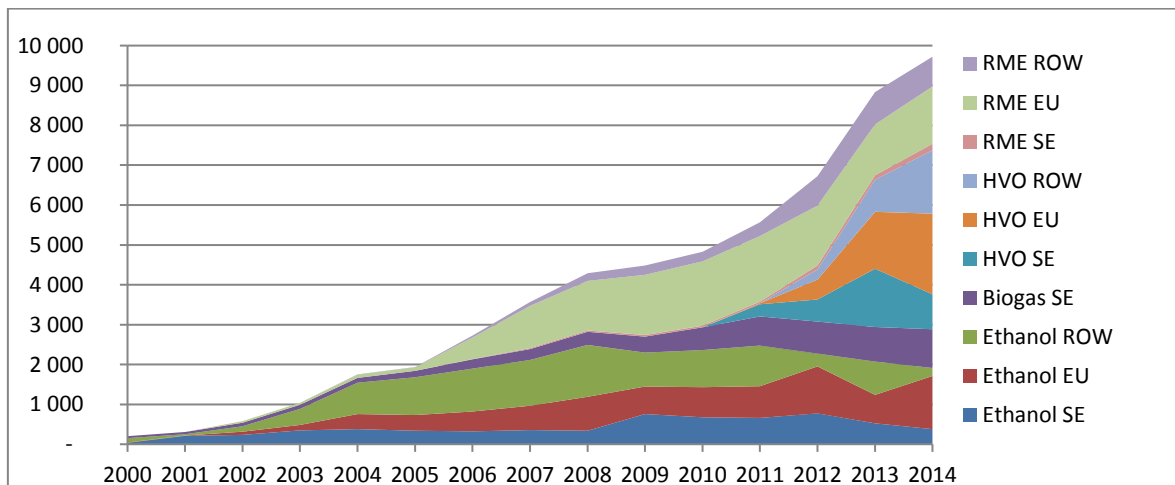


Figure 2. Production region for different fuels consumed in Sweden 2000-2014.

Table 1 reviews the share of raw materials used to produce the fuels during the period. Results demonstrate that a significant share of raw materials used to produce biofuels are produced abroad. For example over the period 2000-2014, roughly 72% of raw materials used to produce biofuels consumed in Sweden were produced abroad.

Table 1: Origin of raw materials used to produce fuels consumed in Sweden between 2000 and 2014, measured in % annually. ACC-Accumulated impacts for each region for the period 2000-2014.

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	Acc
SE	39%	88%	56%	44%	29%	26%	21%	18%	16%	27%	27%	31%	33%	34%	25%	28%
EU	6%	3%	21%	17%	26%	25%	38%	47%	49%	49%	49%	44%	47%	39%	49%	43%
ROW	55%	9%	23%	39%	45%	50%	41%	35%	35%	24%	24%	25%	20%	28%	26%	29%

Figure 3 provides an example of the raw material portfolio to display the origins for ethanol fuel consumption in Sweden. Further examples are provided in the scientific article from this project.

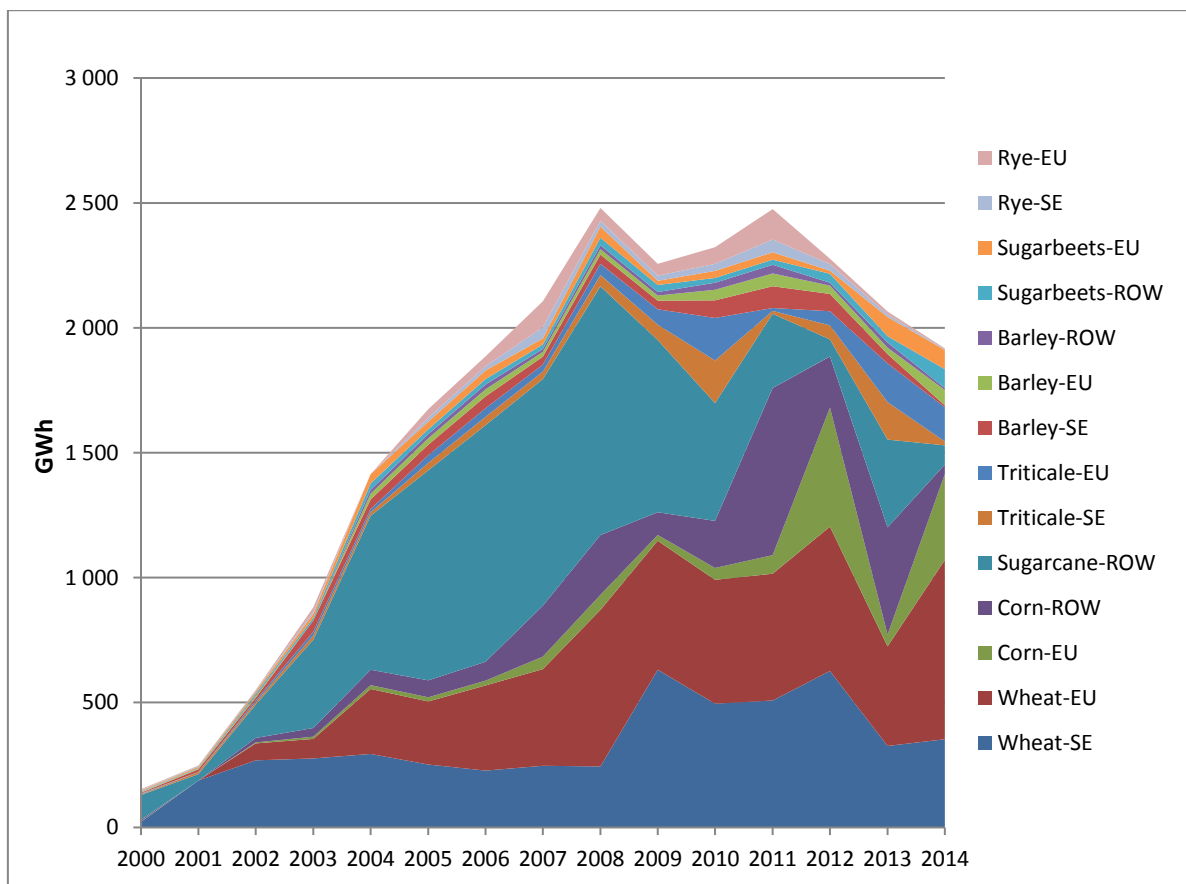


Figure 3. Raw material origins for ethanol production 2000-2014, measured in GWh of final ethanol.

3.2 ENVIRONMENTAL IMPACTS

Figures 4 and 5 provide a review of the local and global impact potential created from the consumption of biofuels, i.e. eutrophication and global warming potential respectively. As illustrated, a large share of GWP is created originating from European raw material and biofuel production. This is due to the use of European crops and fuel production in Europe.

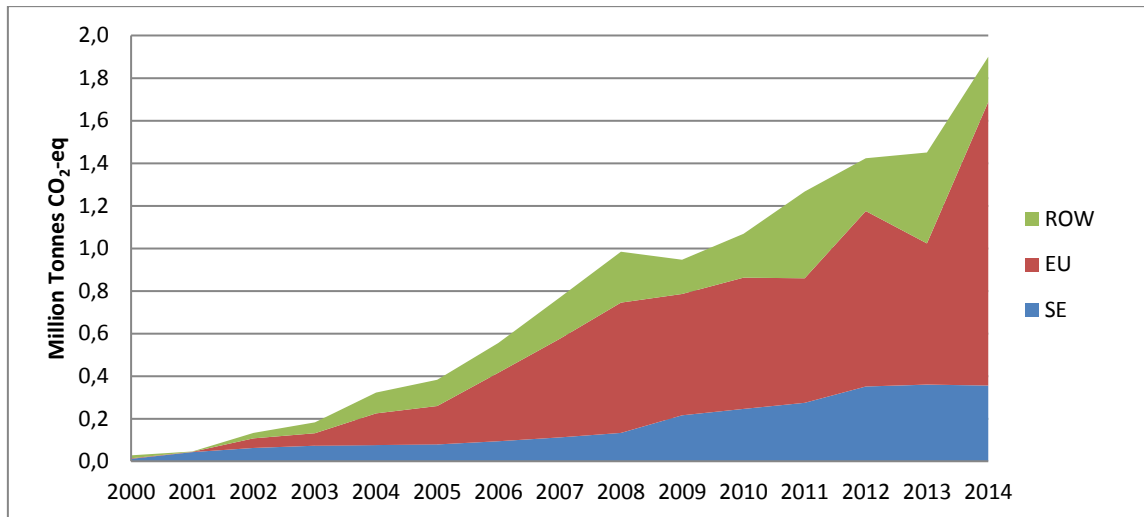


Figure 4. Origin of GHG Emissions for Swedish Biofuels measured in Million Tonnes CO₂-eq.

Thereafter, Figure 5 reviews the Marine eutrophication potential created from biofuel consumption during the studied period. As illustrated, a large share of this corresponds to, and is created abroad, primarily in Europe. Further information related to local impacts is provided in the submitted scientific manuscript.

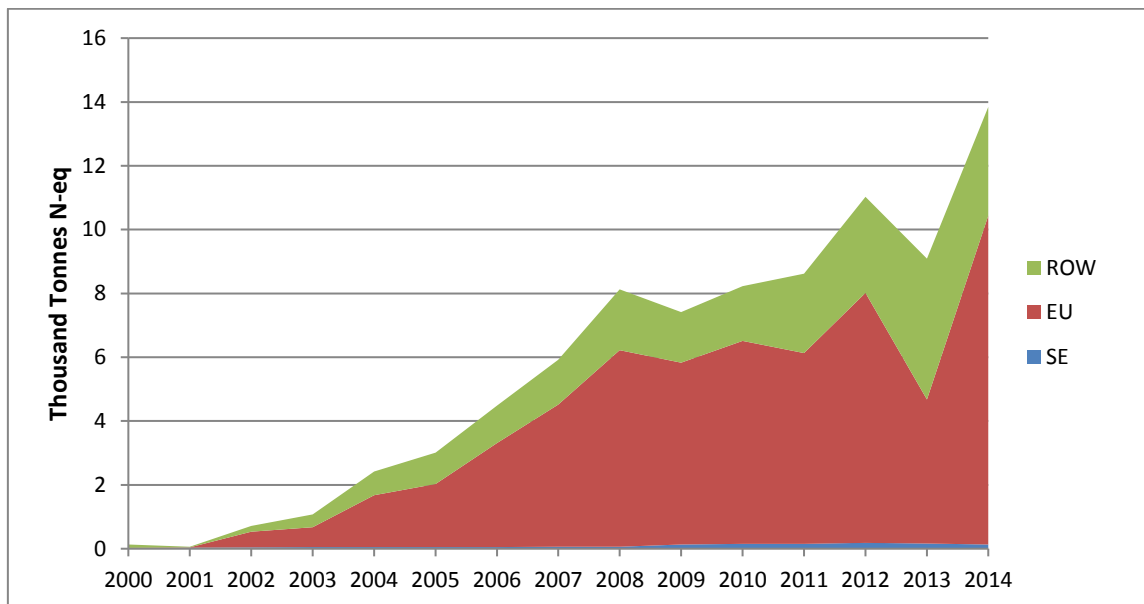


Figure 5. Marine Eutrophication Potential (Measured in Thousand tonnes N-eq).

Figure 6 also provides a review of the accumulated impact potential created during the studied period.

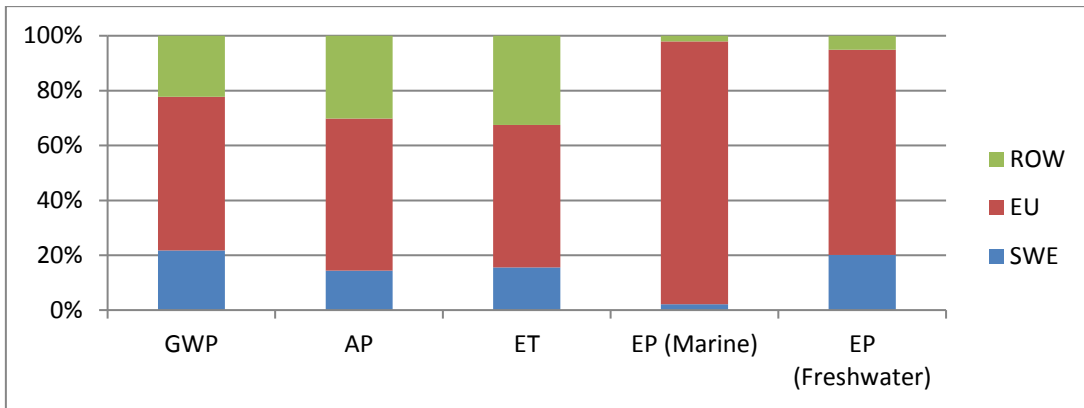


Figure 6. Accumulated Impacts, Well-to-tank (WTT) based on origin of fuels and raw materials.

Figure 7 provides a review of the emissions savings by replacing an equivalent amount of fossil fuels with biofuels. The analysis reviews the GHG emissions that would have occurred if no biofuels were used with fossil average emissions and the relative reductions due to the use of biofuels.

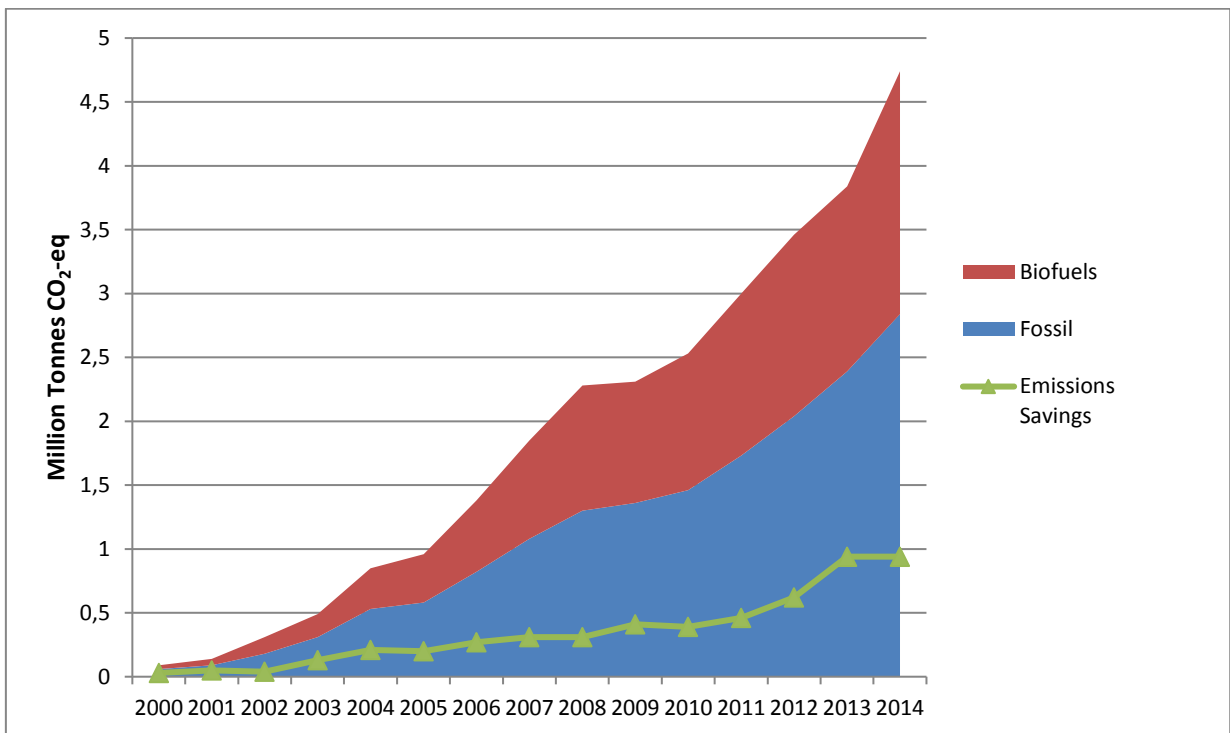


Figure 7. Counterfactual assessment for consumption of equivalent amounts of Fossil Fuels and Biofuels to compare the GHG emissions. Measured in Million Tonnes CO₂-eq emissions.

In 2014, the use of biofuels in place of fossil equivalent fuels replaced roughly 1 Million Tonnes of CO₂-eq emissions and has led to a reduction of over 5 Million Tonnes of CO₂-eq emissions during the studied period. Further analysis on the contributions of the different fuels, annual local impacts created and impacts per fuel mix from each studied regions, etc. are provided in the submitted scientific manuscript

4. CONCLUSIONS

This project provides a comprehensive review of the origins of fuels and raw materials and the environmental implications of biofuel consumption in Sweden. The results illustrate that a large increase in biofuels has occurred, due in part to a large increase in the consumption of HVO and a steady increase in biogas production. The consumption of biodiesel and ethanol, although with a large increase since 2000, have steadily stagnated.

European produced fuels have increased their share in the Swedish biofuel mix in the past years, and together with fuels imported from other nations abroad, currently make up the majority of biofuels consumed. The results also indicate that a substantial share of raw materials used for biofuels consumed in Sweden is produced abroad, which has important environmental implications. The environmental assessments illustrate that the use of biofuels has, by replacing fossil fuels, reduced direct GHG emissions. Nonetheless, during the studied period, the contribution of other environmental impact potential categories has increased abroad. Marine and freshwater eutrophication have increased significantly due to the increase in biofuel imports from Europe. Additionally, local impacts such as toxicity potential and acidification potential have increased abroad due to increased imports of raw materials for biofuel production in Sweden and Europe. Despite, the competitive environmental performance of Swedish biofuels, imports of fuels have continued to increase; coupled exports of domestic produced fuels. Domestically produced ethanol is currently exported, with exports expected to continue, despite its beneficial environmental performance.

This study suggests that while biofuel policy promotes the use of biofuels for reducing fossil fuel use and reducing GHG emissions, it is important to understand the implications and effects this may have abroad. This calls for a review, not only of the environmental performance related to the carbon footprint of the fuels, but of the impacts created by the trade of raw materials and fuels and the relative benefits provided by domestic production. Such reviews are important to include in order to address policy design and in order to meet goals and targets for reduced environmental impacts from Swedish production and consumption. It is suggested that the incentives and barriers created by different policy instruments are reviewed in order to in order to synchronize national consumption targets, environmental objectives, policies and development strategies to guide future policy development to ensure a more sustainable biofuel market for Swedish transportation fuels in the future.

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