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ENVIRONMENTAL AND SOCIO-ECONOMIC BENEFITS OF SWEDISH BIOFUEL PRODUCTION

Extended summary report from a project within the collaborative research program *Renewable transportation fuels and systems*

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THE SWEDISH KNOWLEDGE CENTRE
FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This project is financed and carried out within the f3 and Swedish Energy Agency collaborative research program *Renewable transportation fuels and systems* (Förnybara drivmedel och system).

f3 Swedish Knowledge Centre for Renewable Transportation Fuels 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 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 summary is based on two scientific papers and a separate report:

Martin M, Wetterlund E, Hackl R, Holmgren K, Peck P (2017). *Assessing the aggregated environmental benefits from by-product and utility synergies in the Swedish biofuel industry* (Manuscript to be submitted to the scientific journal "Biofuels").

Peck P (2017). *Jobs and co-benefits from transport biofuels? A review of numbers behind the rhetoric* (Manuscript to be submitted to the scientific journal "Biofuels").

Peck, P. (2017) *Emerging quantifications of key socio-economic metrics: A supporting analysis for the project* "Environmental and Socio-Economic Benefits from Swedish Biofuel Production." (Report to be published by f3 centre.)

This extended summary report shoud be cited as:

Martin, M., *et. al.*, (2017) *Environmental and socio-economic benefits of Swedish biofuel production.* Report No 2017:01, f3 The Swedish Knowledge Centre for Renewable Transportation Fuels, Sweden. Available at www.f3centre.se.

SUMMARY

Significant focus has previously been directed toward investigating the life cycle impacts and negative socio-economic effects of biofuel production. However, a narrow focus on impacts may fail to capture the value of biofuel production. Specifically, there a range of additional benefits that can accrue in both environmental and socio-economic spheres. This study has quantified and analyzed environmental benefits, and reviewed and documented socio-economic benefits of biofuel production in Sweden. It contributes updated and new knowledge of non-fuel related benefits from biofuel production systems, with the aim to improve the decision-base for biofuel producers and policy makers.

The environmental assessment was performed by assessing benefits from relevant biofuel production processes. This included (1) a mapping of the Swedish biofuel production portfolio (current as well as concepts under development) and mapping of the by-products, utilities and services generated, (2) developing future scenarios for total Swedish biofuel production, and (3) the application of life cycle assessment methodology to assess the environmental performance of the production processes, with special focus on the potential benefits from replacing conventional products and services with by-products and utilities from biofuel production. The socio-economic assessment involved a screening of job creation and economic assessments and a review of methods for quantifying other benefits. This included the review and normalization of metrics for job creation delineation of as well as methods used for enumerating job creation, wealth creation, and a limited suite of ancillary environmental or socio-economic benefits. This includes a review of studies of national, sector specific and project level benefits.

The results from the environmental analysis provide evidence that failure to account for non-fuel related benefits from biofuel production leads to an underestimation of the potential for biofuels to contribute to GHG emission reductions when replacing fossil fuels due to the many valuable by-products and/or co-produced utilities with high fossil replacement potential. Prime examples of such being by-products from grain based ethanol production, biogas production digestate, and utility integration of lignocellulosic fuel production (such as gasification based fuels). With the current Swedish biofuel production portfolio, consideration of non-fuel related benefits could lead to 50% greater GHG emission savings, compared to when only considering the replaced fossil fuels. In the considered future fuel production mix scenarios the corresponding number could almost reach 90%, due to significantly increasing shares of biogas and lignocellulosic biofuels. While biofuels have large potential to contribute to reduced GHG emissions, the production of them may lead to other negative environmental impacts, in particular regarding acidification and eutrophication. However, when considering the impact from by-products and utilities, also acidification and eutrophication impacts are reduced, although not as dramatically as for GHG emissions.

The results from the socio-economic review show that an indicative figure of one full time employment per GWh of fuel production appears to be representative across the biofuels reviewed, while regional domestic product gains converge toward an indicative figure of around 1 MSEK per GWh of fuel. Values generated for other co-benefits were also reviewed – including human health, climate, and resource efficiency – add significant benefit over and above the job-related and economic items indicated above.

In summary, the results from this study confirm that the potentially large environmental and socio-economic benefits from biofuel production may provide significant additional value to Swedish biofuel production, today as well as in the future.

SAMMANFATTNING

Betydande fokus har tidigare riktats mot att undersöka livscykeleffekter såväl som negativa socio-ekonomiska effekter relaterade till biodrivmedelsproduktion. Med ett alltför snävt fokus riskerar dock miljömässiga och socioekonomiska värden från biodrivmedelsproduktion att förbises. Denna studie har fokuserat på att kvantifiera och analysera miljöfördelar samt även granska socioekonomiska fördelar med produktion av biodrivmedel i Sverige. Studien bidrar med uppdaterad och ny kunskap om icke-bränslerelaterade fördelar från produktionssystem för biodrivmedel, i syftet att förbättra beslutsunderlaget för biodrivmedelsproducenter och politiska beslutsfattare.

Den miljömässiga bedömningen genomfördes genom att utvärdera nyttan av relevanta produktionsprocesser för biodrivmedel. Detta inkluderade (1) en kartläggning av den svenska produktionsportföljen av biodrivmedel (nuvarande produktion såväl som koncept under utveckling) inklusive biprodukter och tjänster som genereras vid produktionen, (2) utveckling av framtidsscenarier för total biodrivmedelsproduktion i Sverige, och 3) tillämpning av livscykelanalyser för att bedöma produktionsprocessernas miljöprestanda, med särskilt fokus på eventuella fördelar från att ersätta konventionella produkter och tjänster med biprodukter och t.ex. överskottsenergi (engelska ”utilities”) från biodrivmedelsproduktion. Den socioekonomiska bedömningen innefattade en genomgång av utvärderingar av jobbskapande samt en översyn av metoder för att kvantifiera andra fördelar. Detta inkluderade en granskning av statistik över skapade arbetstillfällen, såväl som av de metoder som används för att kvantifiera sysselsättning, välstånd och ”andra” miljörelaterade eller socioekonomiska fördelar. Studier av fördelar på nationell, sektorsspecifik och projektnivå granskades.

Resultaten från den miljömässiga analysen visar att om hänsyn inte tas till icke-bränslerelaterade fördelar från produktion av biodrivmedel kan detta leda till en generell underskattning av biodrivmedlens potential att bidra till minskningar av växthusgasutsläpp när de ersätter fossila bränslen, på grund av de många värdefulla biprodukter och/eller ”utilities” som uppkommer vid biodrivmedelsproduktionen och som i sin tur kan ha hög fossilersättningspotential. Tydliga exempel inkluderar biprodukter från spannmålsbaserad etanolproduktion, rötrester från biogasproduktion, och värmeintegration för lignocellulosabaserad drivmedelsproduktion (som t.ex. förgasningsbaserade bränslen). Med den nuvarande sammansättningen av svensk biodrivmedelsproduktion kan upp till 50% större minskning av växthusgasutsläpp identifieras om hänsyn tas även till icke-bränslerelaterade fördelar, jämfört med om endast de ersatta fossila bränslena beaktas. Motsvarande siffra för de studerade scenarierna för framtida bränslemixar kan uppgå till nästan 90%, på grund av signifikant högre andelar biogas och lignocellulosabaserade bränslen. Även om biodrivmedel har en betydande potential att bidra till minskade växthusgasutsläpp, kan produktionen av dem leda till oönskad inverkan på miljön i form av exempelvis försurning och övergödning. När hänsyn tas till effekter från samproducerade biprodukter och energitjänster minskar även försurnings- och övergödningseffekterna, även om inverkan inte är lika utpräglad som för växthusgasutsläpp.

Resultaten från den socioekonomiska granskningen visar att en indikativ siffra på en heltidstjänst per GWh producerat biodrivmedel tycks vara representativt över de granskade biodrivmedlen, medan regionala vinster från inhemsk produktion konvergerar mot en vägledande siffra på cirka

1 MSEK per GWh bränsle. En genomgång gjordes även av andra värden från biodrivmedelsproduktion, såsom människors hälsa, klimat och resurseffektivitet, vilka kan ge ytterligare betydande fördelar utöver de arbetsrelaterade och ekonomiska värdena.

Sammanfattningsvis bekräftar resultaten från denna studie att de potentiellt stora miljömässiga och socioekonomiska fördelarna från produktion av biodrivmedel kan ge upphov till betydande mervärde från svensk biodrivmedelsproduktion, idag såväl som i framtiden.

1 BACKGROUND

There is significant ongoing debate in both political and academic spheres regarding the environmental and social impacts of biofuel production. Much focus has been directed toward investigating the negative life cycle environmental impacts in addition to considerable attention upon negative socio-economic effects that may arise related to biofuel production abroad. To provide a balanced view, it is thus important to portray and, where feasible, quantify potential advantages of Swedish biofuel production. This study has quantified and analyzed environmental benefits and reviewed socio-economic benefits of biofuel production in Sweden, so as to improve the decision-base for biofuel producers and policy makers. It contributes updated and new knowledge of non-fuel related benefits from biofuel production systems.

1.1 METHODOLOGY

Assessing environmental benefits

The environmental review was performed by assessing benefits from relevant biofuel production processes. Three main steps were applied: 1) a review of the current Swedish biofuel production portfolio and mapping of the by-products, utilities and services generated; 2) a review and selection of potential future biofuel production pathways and technological production concepts – that also incorporate/estimate impact of by-products, utilities and services; and 3) the application of life cycle assessment methodology to deliver both: a quantification and assessment of the environmental performance of the production processes; and assessment of the impact of replacing conventional products and services with by-products and utilities from biofuel production. In the scenarios, two different time perspectives have been applied for the aggregated analysis. These include a current (2015) and a medium-term future (2030) perspective. The latter incorporates different levels of ambition (i.e. ambitious and cautious) for future domestic biofuel production.

Assessing socio-economic benefits

The socio-economic work involved a screening of job creation assessments and a review of methods for enumerating other benefits. The screening review focused on metrics for job creation. The method assessment review was broader and included methods for counting job creation, wealth creation, and enumerating ‘other’ environmental or socio-economic benefits. This required a review of studies of 1) national level benefits, 2) benefits delivered by a specific sector, project, or projects, 3) biofuels-related metrics for employment/economic stimulation and 4) energy security and environmental benefit valuation.

2 RESULTS

2.1 ENVIRONMENTAL ASSESSMENT

Fuel production scenario

Domestic biofuel production in Sweden amounts to around 5 TWh per year. This corresponds to just over a third of the total biofuel usage Sweden in 2015. The future scenarios worked with figures of ca. 28 TWh and 13 TWh for the ambitious and cautious scenarios respectively (Figure 1). Current agriculture based biofuel production was assumed to remain at current levels, with expansion mainly for waste or cellulosic feedstock based biofuels. For advanced biofuel production, only technologies that have reached at least pilot or demonstration scale, and where plans for actual commercial operation either exist or have existed in Sweden, were considered to increase in future scenarios.

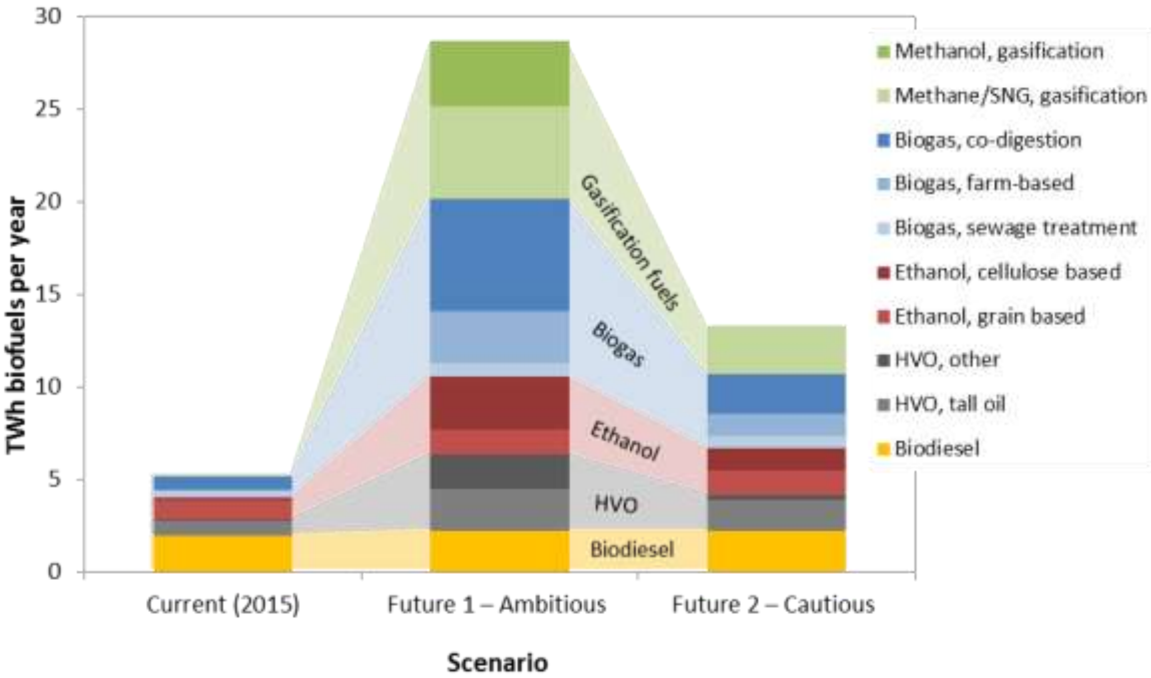
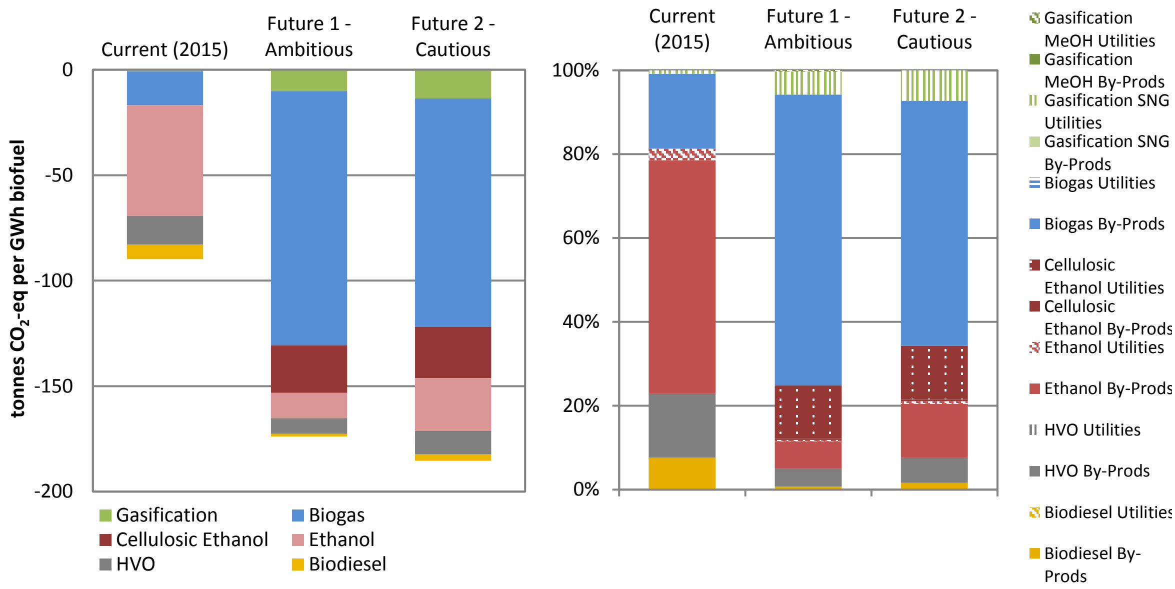


Figure 1. Overview of the three analyzed biofuel production scenarios.*
*** 'Biogas' is used do denote methane from anaerobic digestion, while methane from biomass gasification (thermochemical conversion) is denoted 'Methane/SNG, gasification'.**

Assessment of environmental benefits

In absolute terms, the largest greenhouse gas (GHG) emission benefits for the Current scenario (2015) were found to originate from by-products from grain based ethanol production (from e.g. avoided fodder and conventional carbon dioxide production).These contributed to more than half of the total avoided GHG emissions (Figure 2a, b.) This was followed by reductions arising from biogas and HVO by-products. The largest benefits indicated by future scenarios are for biogas by-products. This is largely due to large benefits for avoided conventional fertilizer production; contributing with up to 70% of the total avoided GHG emissions. This is in both scenarios followed by replacement of utilities (heat and electricity) from cellulosic ethanol and gasification fuels in addition to grain based ethanol by-products. Cellulosic ethanol showed a larger share of avoided GHG emissions than the gasification based fuels, despite the smaller share of production. Here this is due to a relatively low yield of the main product (cellulosic ethanol) and corresponding high yield of by-products and utilities. The latter items have relatively higher fossil energy replacement potential than gasification-based fuels, where the biomass to biofuel yield is instead significantly higher (Figure 2b).



(a) (b)

Figure 2a-b. Avoided greenhouse gas emissions from by-products and utilities per GWh of produced biofuels annually, (b) review of the contribution of by-products and utilities from the different sectors to the overall benefits provided annually.

Figure 3 shows a comparison of GHG emissions related to current and biofuels production acc. to the two scenarios, with the equivalent emissions from fossil fuels. In the two future scenarios a significant potential for reducing GHG emissions by replacing equivalent amounts of fossil fuels with biofuels can be seen. Of this, large reductions can be attributed to benefits from by-products and utilities (Figure 4a).

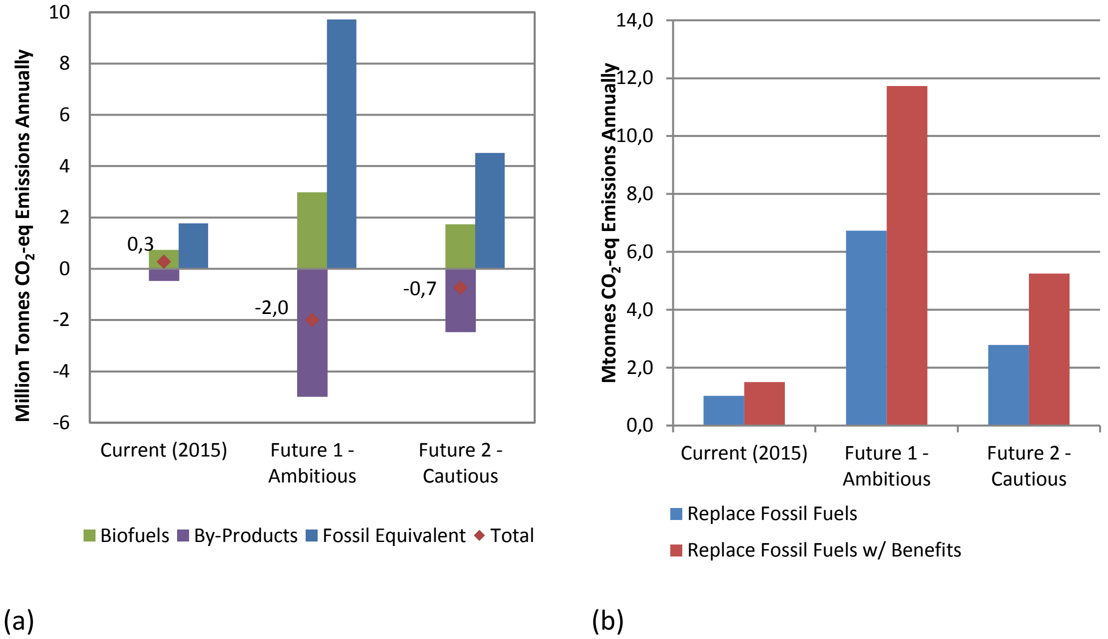


Figure 4a-b. Resulting aggregated environmental impacts from biofuels and by-products. 'Total' - sum of impact from biofuel production and credits for by-products and utilities. Fossil equivalent impacts are shown for comparison. b) Contribution of Swedish produced biofuels (shown with and without credits for by-products and utilities) for reducing GHG emissions through the replacement of equivalent amount of fossil fuels.

Socio-economic assessment

The socio-economic assessment provides: insights on the methods used, in Sweden and abroad, to quantify socio-economic benefits; the form of metrics applied; and the relative scale of valuations for socio-economic benefits relevant to Swedish biofuel production systems. It was found that national level assessments generally build upon equilibrium or partial equilibrium models for the agricultural and energy sectors. These often compare different (candidate) policy tools against each other *ex ante*. Using input-output modelling, they gauge the effects of a new (expanding) biofuels sector upon other parts of the economy counting both 'positives' and 'negatives' across the economy. Such include overall welfare effects, labour market effects, and economic revenues, or combinations of these. Importantly, the studies examined in this analysis indicated that new biofuels industries create new employment opportunities, and financial benefits at national levels, that exceed the costs of support to the sector.

At the level of specific sector, project or group of projects, the assessments reviewed have two main categories: 1) 'bottom-up' exercises conducted in liaison with biofuel industries in a specific sub-region; 2) application of regional analyses forecasting and modelling with software linked to regional demographic and economic databases. Most bottom-up assessments focus only upon direct and indirect employment opportunities, and direct economic effects. Modelling exercises most often include induced employment effects over and above these metrics. While they can also provide details of economic metrics (e.g. regional level 'domestic product'), some modellings limit this to business turnover or wages. Results drawn from both bottom up and modelling exercises are summarised below in Table 1. All values have been normalised to annual full time equivalent (FTE) employment opportunities per TWh or GWh of produced fuel.

Table 1. Direct and Total FTE/TWh and Regional Domestic Production Stimulation (MSEK/GWh) based on Swedish and International Ethanol, Biodiesel and Biogas Initiatives.

	Direct Employment Effects (FTE/TWh)	Total Employment Effects (FTE/TWh)	Regional Domestic Product Stimulation (MSEK/GWh)
Ethanol[1]	40-80	450-1100	0.75-1.5
Biodiesel[2]	10-380	1000-1200	2.3
Biogas[3]	200-850	300-1400	0.5-2

[1] **Based on International and Swedish Ethanol Initiatives**
[2] **Based on International (US) and Swedish biodiesel initiatives**
[3] **Based on Swedish Biogas Initiatives.**

This work also demonstrates that a growing suite of ancillary benefits is now entering into mainstream use. The most prominent focus at the national level in Sweden, in this category, is CO_2. However, evaluations are also produced at sub-regional or local levels for other environmental benefits, *inter alia*: reductions of methane, nitrous oxides, and particulate emissions; reduced leakage of nitrates to groundwater; and the value of replaced feed and fertilizers. Such have been applied in a number of biofuels studies generated for regional decision-making, chiefly building on results of LCA studies. A compilation and comparison of selected Swedish metrics and quantifications environmental gains are summarised in Table 2.

Table 2. Ancillary environmental socio-economic metrics applicable in Sweden.

Emissions reductions	SEK per (varying) unit	$USD_{(9,05)}$
CO_2 reduction C_{tax} on transport C_{tax} other sectors International value	1.5kr/kg 1.02kr/kg 0.2kr/kg	US$ 0.17
NOx reduction (source animal manure)	32, 00 kr/MWh	US$ 3.54
Nitrogen leakage to groundwater	5,4 kr/MWh	US$ 0.60
Methane reduction (see CO_{2equiv})	71,64 kr/MWh	US$ 7.92
Replaced mineral fertilisers $13KgCO_{2equiv}/tonne_{digestate}$	13,3 $kr/t_{digestate}$	US$ 1.47/$t_{digestate}$
Energy security (displaced fossil fuel import)	15 kr/MWh	US$ 1.66
Particulate Emissions	400 kr/kg_{rural} 2000 kr/kg_{towns} 4000 kr/kg_{cities}	US$ 44.34 US$ 222 US$ 443
Particulate emissions City example (biogas from household/industry waste)	Car: 9.36kg/GWh_{biogas} 37.4 kr/MWh Truck: 20.88Kg/GWh_{biogas} 83.5 kr/MWh	US$ 4.13 US$ 9.23

3 CONCLUSIONS

From an environmental perspective it can be concluded that failure to account for non-fuel related benefits from biofuel production will lead to underestimation of the potential for biofuels to contribute to GHG emission reductions when replacing fossil fuels. This is particularly valid for biofuels where the production systems are designed to deliver by-products and/or co-produced utilities with high fossil replacement potential. Prime examples of such being by-products from grain based ethanol production, biogas production digestate, and utility integration with cellulosic and gasification fuels. In some cases, the avoided emissions from replacing fossil products and energy sources can be larger than the emissions produced from the fuel production; e.g. as seen with the example of biogas and the value of replacing conventional fertilizers.

This analysis has examined Swedish transport biofuels production and identified and enumerated a range of ancillary socio-economic benefits. In this analysis, indicative spans of metrics for both job and wealth creation and how these have been derived are documented. Moreover, emerging metric sets, and general assessment methods for other socio-economic and environmental benefits have been identified. For employment, an indicative figure of 1 FTE across a biofuel value chain per GWh of fuel production appears to be representative, while regional domestic product gains converge toward an indicative figure of circa 1MSEK/GWh of fuel as a key economic figure. Values generated for other co-benefits – including human health, climate, and resource efficiency – also appear to be entering mainstream use. Such figures are generally draw upon LCA work and are thus presumably highly reliant upon robust LCA data. Importantly in the context of this work, such items also appear to add a significant benefit over and above the job-related and economic items indicated above.

In summary, the results from this study confirm that the potentially large environmental and socio-economic benefits from biofuel production in Sweden may provide significant additional value to Swedish biofuel production, today as well as in the future.

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