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PROFITABILITY AND GREENHOUSE GAS EMISSION REDUCTION POTENTIAL FOR GASIFICATION-BASED BIOFUELS

– COMPARISON TO ELECTRICITY IN TRANSPORT BY CONVENTIONAL CONVERSION OF BIOMASS

Report from an f3 project

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THE SWEDISH KNOWLEDGE CENTRE
FOR RENEWABLE TRANSPORTATION FUELS

PREFACE

This report is the result of a collaborative 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 and the region of Västra Götaland. f3 also receives funding from Vinnova (Sweden's innovation agency) as a Swedish advocacy platform towards Horizon 2020. f3 also finances the collaborative research program Renewable transportation fuels and systems (Förnybara drivmedel och system) together with the Swedish Energy Agency. Chalmers Industriteknik (CIT) functions as the host of the f3 organization (see www.f3centre.se).

This report is an extended summary of the f3 project ”Gasification based biofuels – greenhouse gas emissions and profitability analysis with general and sector specific policy instruments”.

Based on a previous comprehensive system analysis study (Holmgren, Berntsson et al. 2016) this project has analyzed the required level of a sector specific CO_{2e}-cost for making the Net Annual Profit (NAP) of the gasification-based systems positive under different future energy market scenarios.

The main outcome and full presentation of results from the project is documented by a manuscript submitted for publication in Energy:

Holmgren et al. (Submitted). *Gasification based biofuel production - sector specific policy instruments and comparison of greenhouse gas emissions reduction potentials of conventional biomass conversion technologies*. Energy.

Additional funding for the project has been provided by Göteborg Energi foundation for research and development.

This report should be cited as:

Holmgren, K.M., et al., (2017) *Profitability and greenhouse gas emission reduction potential of gasification based biofuels – comparison to electricity in transport by conventional conversion of biomass.* Report No 2017:18, f3 The Swedish Knowledge Centre for Renewable Transportation Fuels, Sweden. Available at www.f3centre.se.

SUMMARY

Gasification-based biofuel production systems have a large potential to contribute to climate change mitigation in the transport sector. The commercial feasibility of renewable energy technologies is affected by fossil fuel prices, the price of biomass and policy instruments, e.g. a CO_{2e} cost.

The aim of this project is to analyze and quantify the level of a sector specific greenhouse gas (GHG) emission cost (CO_{2e} cost) in transport required for making gasification-based biofuel production systems profitable under different future energy market scenarios.

The analysis of the gasification-based systems builds upon the earlier work by Holmgren, Berntsson et al. (2016) and Holmgren (2015) and includes production systems of SNG (synthetic natural gas), methanol and Fischer-Tropsch fuels. The future energy market scenarios are based on the fossil fuel prices in the ”New Policy Scenario” and ”450 ppmv Scenario” presented in World Energy Outlook 2016 (IEA 2016).

The analysis in this project also includes a comparison of the profitability and GHG emission reduction potential from the gasification based systems to systems where the same amount of biomass is used in conventional conversion technologies to produce electricity and where the electricity is used in battery electric vehicles (BEV).

The results show that the level of the sector specific CO_{2e} cost required to make the gasification-based systems profitable is not higher than the current level of CO_2 tax in Swedish transport sector.

The results also show that the systems where the biomass is used for electricity production and in BEV have higher profitability than the gasification-based systems. However, the electricity –based systems have a stronger dependency on heat sinks and a high price for delivered heat.

The analysis of the GHG emissions indicates that the electricity.-based systems also result in higher emission reductions than the gasification-based systems. However, the study does not include all parts of the system (not vehicle and battery production and not infrastructure for charging). Also in this analysis the heat sinks are of importance along with the higher efficiency of electric motors compared to diesel and Otto-engines.

Future studies comparing advanced biofuels and BEV should cover emissions from production of vehicles, batteries, and charging infrastructure as well as the influence of BEV on the electricity system. These topics have not been included in this study.

The main contributions from this study are that:

- the gasification-based systems do not require an unreasonably high CO_{2e} cost to be profitable and
- electricity based systems have higher profitability but stronger dependency on heat sinks and a high price for delivered heat
- the GHG emission reduction potential for electricity-based systems seems to be higher than for the gasification based systems – but the importance of heat sinks and emissions from battery and vehicle production should be fully considered.

SAMMANFATTNING

Förgasningsbaserade biodrivmedelproduktionssystem har en stor potential att minska utsläppen av växthusgaser. Den kommersiella genomförbarheten för dessa system påverkas av fossilbränslepriser, priset på biomassa samt politiska styrmedel, t.ex. kostnaden för att släppa ut koldioxid.

Syftet med projektet är att analysera och kvantifiera vilka nivåer på en sektorsspecifik kostnad för växthusgasutsläpp (CO_{2e}-kostnad) i transportsektorn som krävs för att få lönsamhet i olika förgasningsbaserade biodrivmedelssystem under olika framtida energimarknadsscenarier.

Analysen av de förgasningsbaserade systemen bygger på tidigare arbete av Holmgren, Berntsson m. fl.. (2016) samt Holmgren (2015) och inkluderar produktion av SNG (syntetisk naturgas), metanol och Fischer-Tropsch bränslen. Framtidsscenarierna baseras på de priser för fossila bränslen som anges i ”New Policy Scenario” samt ”450 ppmv Scenario” i World Energy Outlook 2016 (IEA 2016).

I projektet jämförs också kostnader och utsläpp av växthusgaser från de förgasningsbaserade systemen med system där biomassa istället används för elproduktion (kraftvärme eller kondenskraft) och där elen används för fordonsdrift.

Resultaten visar att den sektorspecifika kostnaden som skulle krävas för att de förgasningsbaserade system skall bli lönsamma inte är högre än den nuvarande koldioxidskatten för drivmedel i Sverige.

Resultaten visar också att de system där biomassan används i konventionella omvandlingssystem till el och där elen används för fordonsdrift har högre lönsamhet i de undersökta scenarierna. Dock är dessa system starkt beroende av värmesänkor och intäkter från levererad värme till ett högt pris.

När det gäller analysen av växthusgasutsläpp ser det också ut som om systemet med eldrift ger större reduktioner än de förgasningsbaserade systemen. Dock inkluderar analysen inte systemets alla delar (ej fordons- och batteritillverkning samt ladd-infrastruktur). Även här spelar värmesänkor en betydande roll, men också den högre effektiviteten hos elmotorer jämfört med diesel och bensinmotorer.

Framtida forskning och jämförelse av avancerade biodrivmedel och elfordon bör inkludera utsläpp från produktion av fordon, batterier och ladd-infrastruktur. Dessa områden har inte täckts in i denna studie.

De främsta bidragen från denna studie är att:

- de förgasningsbaserade systemen inte kräver en orimligt hög CO_{2e}-kostnad för att vara lönsamma
- att de elbaserade system har högre lönsamhet men större beroende av värmesänkor och pris på värme
- även växthusgasreduktioner verkar vara högre för de elbaserade systemen, men även här spelar värmesänkor roll och emissioner från batteri och fordonstillverkning.

Studien i sin helhet samt resultat presenteras i ett manuscript som är skickat för publicering i Energy (Holmgren et al. (submitted)).

ABBREVIATIONS

BEV	battery electric vehicles
CCS	carbon capture and storage
CHP, bio-CHP	Combined heat and power, biomass fueled combined heat and power
CO_{2e}	Carbon dioxide equivalents
DH	District heating
FT	Fischer-Tropsch
GHG	Greenhouse Gas
GWP	Global Warming Potential
IC	Investment cost
ICE	Internal Combustion Engine
INT	Integrated
LCA	Life cycle assessment
MeOH	Methanol
MW	Mega watt
NAP	Net annual profit
O&M	Operation and maintenance
ppm_v	parts per million by volume
SA	Stand alone
SNG	synthetic natural gas

CONTENTS

1 INTRODUCTION

1.1 BACKGROUND

The project ”*Advantages of regional industrial cluster formations for the integration of large scale biomass gasification*” (Holmgren 2015) analyzed how the integration of new large scale biomass gasification systems into existing industrial infrastructure impacted the systems total greenhouse gas emissions and economy (biofuel production costs and net annual profit – NAP). The analyzed system included both stand-alone gasification units and configurations integrated to other industries according to the following case studies (based on the results in (Holmgren, Berntsson et al. 2016):

- SNG (synthetic natural gas) production; integrated to a district heating system and with possibility to distribute the gas via the natural gas net.
- Methanol production integrated to a chemical industrial cluster.
- Fischer-Tropsch-fuel production integrated to a mineral oil refinery.

Holmgren, Berntsson et al. (2016) analyzed the profitabilities of the gasification–based systems for different future energy market scenarios with the assumption that in the future (2030 and 2040) there will be a uniform, sector wide CO_{2e} cost[1]. The results showed that only for a few of the systems, and only under some of the investigated energy market conditions (scenarios), the NAP was positive.

However, the current policy instruments in for instance the Swedish transport sector means that the specific cost for CO_{2e} emissions is significantly higher than in the industry or energy (heat and power) sectors. This motivated a further analysis of how high a sector specific CO_{2e} cost would need to be in order to make the gasification-based system profitable.

During the last few years, several gasification-based initiatives and planned installations have been postponed or put on hold. During the same time, focus on electric vehicles and infrastructure for these vehicles has increased markedly. Since conventional biomass based combined heat and power production is a proven technology widely used in Sweden we found it interesting to compare the profitability and GHG reduction potential of such systems replacing conventional fossil fuels in the transport sector to the gasification based systems.

This report is a short summary of the project, which is fully presented in a manuscript submitted for publication in Energy (Holmgren et al. (submitted).

1.2 AIM

The aim of this project was to analyze the economic performance of gasification-based biofuel production at different levels of general or sector specific policy instruments (CO_2 costs) for different future energy market scenarios. Specifically the aim was to determine the required sector specific

[1] The CO_{2e} cost is a cost for emitting greenhouse gases. The emissions are summarized using the GWP100-values. Sector-wide means that the cost is assumed to be paid independently of where in the supply chain the emissions occur.

(for the transport sector) CO_{2e} cost for making the net annual profit (NAP) of the gasification-based systems profitable under different future energy market scenarios. The project also aimed at comparing costs and greenhouse gas (GHG) emissions for gasification-based biofuel production systems to systems where the biomass is used for power production and the electricity is used in battery electric vehicles (BEV) thereby replacing fossil fuels in the transport sector.

1.3 LIMITATIONS

The present study is a very limited study (small study in monetary terms). The main reason for conducting it was that with only limited resources it would be possible to investigate the required sector specific CO_{2e} level for a set of comparable gasification base biofuel production systems that had been evaluated in a more comprehensive study. Even if sector wide policy instruments might be preferable from a theoretic point of view, practical reasons might make sector specific instruments necessary also in the future. The more comprehensive previous study only included the sector wide CO_{2e} cost and with small efforts it was possible to add the analysis of a sector specific CO_{2e} cost.

The strong interest of electric vehicles in recent years also accentuated a comparison to these systems. This comparison was declared to be made using data available in literature and not with in depth system specific analysis.

2 METHOD

The study includes a profitability analysis for different future energy market scenarios and an analysis of the greenhouse gas emission reduction potential of the gasification based systems and the systems with BEV propelled by electricity from bio CHPs. The methods used in these analyses are described in the following sections.

The analyzed gasification systems are explained in **Fel! Hittar inte referenskälla.**.

Table 1. Case descriptions. For more details on the technologies used, please consult Holmgren & Berntsson et al (2016).

Case	Description
SNG SA	Stand-alone (SA) production of SNG. A heat recovery steam cycle (HRSC) utilizes excess heat from the gasification process for power production.
SNG DH	Same as SNG SA but the HRSC operates in backpressure mode producing heat for district heating (DH)
SNG DH CCS	As SNG DH but the separated CO_2 is compressed and sent for storage.
MeOH SA	Stand-alone production of methanol. Excess heat and off-gases are used in a HRSC for power production.
MeOH INT	Methanol production plant integrated to chemical cluster. LP steam from gasification replaces natural gas in boilers.
MeOH CCS	As MeOH INT but separated CO_2 is sent for storage.
FT SA	Stand-alone production of Fischer-Tropsch fuels.
FT INT	Fischer-Tropsch fuel production integrated to an oil refinery. HP steam from gasification process replaces natural gas combustion in boilers.
FT INT CCS	As FT INT but separated CO_2 is sent for storage.

2.1 PROFITABILITY ANALYSIS

The profitability is evaluated in terms of net annual profit (NAP) in this study. The NAP is determined by:

- the costs for inputs: biomass, electricity, fuel etc. to the production process
- investment costs (IC) and operation and maintenance costs (O&M) for the production installation (gasification unit or bio-CHP)
- incomes for outputs: electricity, useful heat and biofuel

The amounts of inputs and outputs were based on the studies of the gasification-based systems in Holmgren, Berntsson et al. (2016). The prices of the energy commodities were determined by using the energy market scenario tool (ENPAC) described by (Axelsson, Harvey et al. 2009). The tool was updated with data from IEA (2016). The analysis was made for two of the available scenarios; the New Policy scenario and the 450 ppmv scenario and for the years 2030 and 2040.

The IC and O&M were also based on estimates assessed by Holmgren (2015) and used in (Holmgren, Berntsson et al. 2016). Estimates for the bio-CHP systems were based on data from Nohlgren, Svärd Herstad et al. (2014).

A more thorough description of the calculation of the NAP is given in (Holmgren, Berntsson et al. 2016) and in Holmgren, Berntsson et al. (submitted for publication).

The chosen measure for the profitability analysis was the NAP which is a measure interesting for the producers and investors. This measure is therefore interesting in a discussion on whether these installations would be realized or not. Will the technology be interesting for investing?

In contrast, the GHG evaluation was made from a global perspective. The GHG analysis will give an answer to what will be the consequence for the environment if these investments are realized and the installations come into place.

2.2 GREENHOUSE GAS EMISSION REDUCTIONS

The GHG calculations follow the methodology applied in Holmgren, Berntsson et al. (2016) which is described in detail in Holmgren, Berntsson et al. (2015). The GHG emissions are evaluated from a life cycle perspective with a consequential approach. In the present study, the GHG emission reduction of the gasification-based systems (SNG, methanol and Fischer-Tropsch fuel production) are compared to systems where biomass is used in other processes, i.e.:

- one case where it directly replaces coal (e.g. in a coal power plant)
- one case where it is used in bio-CHP with industrial backpressure where the produced steam replaces a natural gas boiler and the electricity is used in the transport sector to replace petrol and diesel (battery electric vehicles replaces conventional vehicles)
- one case where the biomass is used in a condensing bio-power plant and the electricity is used as in the previous case in the transport sector to replace petrol and diesel. [2]

The first case was included also in (Holmgren, Berntsson et al. 2016) and showed the highest GHG emission reduction potential of all biomass systems. In the present study the comparison to both the industrial bio-CHP and the bio condensing routes are new.

2.3 MAIN ASSUMPTIONS

In this study analyses future systems of not yet commercially available technology and therefore includes a lot of assumptions. The assumptions of the gasification base systems are the same as in Holmgren et al. 2016.

The energy market scenarios used in this study are updated compared to the ones used in Holmgren et al. 2016. They are still based on the ENPAC tool but are in this study based on the estimates of IEA World Energy Outlook from 2016.

[2] This case is hypothetical, at least in a Swedish context, but is included as a comparison.

Assumptions in the bio-CHP and BEV system

The comparison to profitability and GHG emission reductions in a system where BEV are used was made in this study to give an orientation on how such systems would come out compared to the gasification based systems. This could be made in many different ways and du to the limited scope of the study two cases with limited sensitivity analysis have been included. Other ways to compare and more sensitivity analysis are interesting for future studies. The present study includes the following assumptions based on the reasoning below:

- The comparison is made for a system where the same amount of biomass is used as in the gasification based systems (3.4 TWh of biomass).
- Conventional (already available production technology was chosen) Another option could have been to compare to gasification based power production BIGCC (biomass integrated gasification combined cycle). However, conventional bio CHP was chosen and this also implies that the size of the installation is smaller. Hence the assumption was that for the set amount of biomass 4.3 installations would be reasonable where syngas is directly fuelled.
- There is a significant difference between the amount of heat delivered form the gasification based systems and the CHP system producing electricity for the BEV. The amount is significantly higher in the case of the CHP. One way of comparing would have been to assume that the bio-CHP would deliver to existing DH systems but since a marginal approach was applied it was hard to motivate several new medium scale CHP for DH in a Swedish context. It seemed more reasonable that industrial installations with heat demand would install new production units for their heat/utility demand. The assumption in this study was therefore that the bio-CHP would deliver LP steam to industry and there replace current natural gas based production. Another option would have been to assume that the bio-CHP would replace some technology in existing DH systems but there is little fossil technologies to replace since most DH already is based on waste (which in general is cheaper than biomass) or biomass. IN a European perspective it is also reasonable to assume that new DH could replace natural gas based production (in general boilers).
- The data on electricity demand in the BEV is entirely based upon data from Hagman et al 2016. It should be noted that the data in Hagman et al 2016 is based on actual energy demand and not demand given by producers.

3 RESULTS

3.1 PROFITABILITY ANALYSIS

The NAPs calculated with the prices of the New Policy scenario for the gasification-based systems were negative for all cases except the integrated FT-fuel production and in the case when the SNG was assumed to be priced as petrol (if priced as natural gas, the NAP was negative also for the SNG route).

In the calculations based on the prices in the 450 ppmv scenario only one case, the SNG DH CCS when SNG is priced as petrol, resulted in positive NAP.

The NAP for the industrial CHP replacing a natural gas boiler was positive for all the energy market scenario points.

The required CO_{2e}-charges for making the NAP of the gasification-based biofuel production systems positive for the two different energy market scenarios are displayed in Figure 1 andFigure **2**:

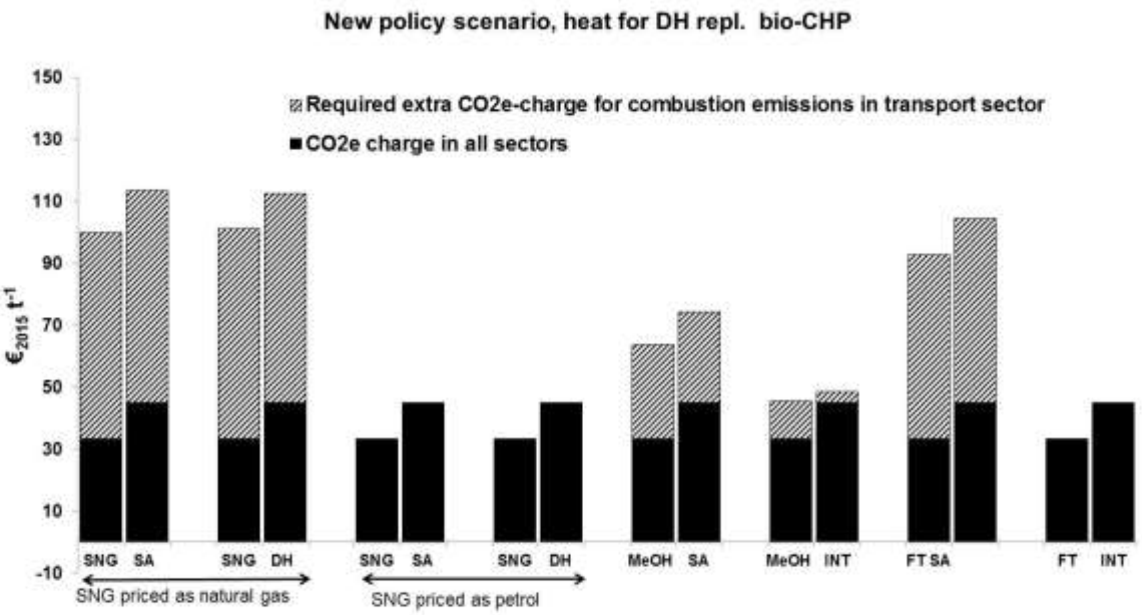

Figure 1. Required sector specific CO_{2e} charge in transport sector for making the NAP of the gasification-based systems positive. The left staple in each pair represents the New Policy scenario 2030 and the right staple is for 2040. The total required CO_{2e} charge is the sum of the sector general and the sector specific costs.

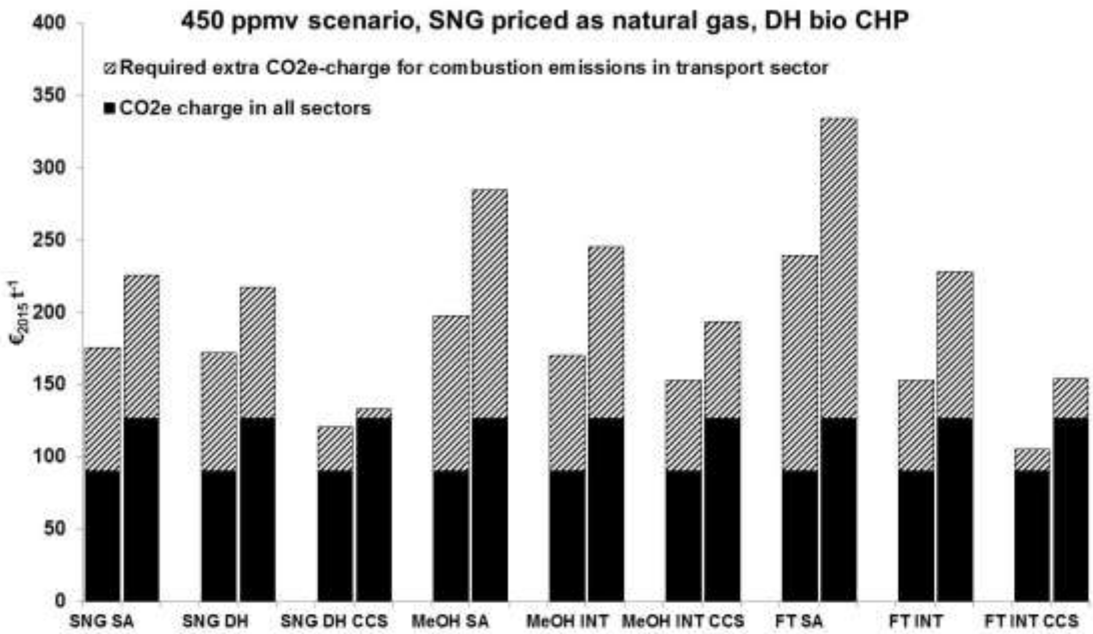

Figure 2. Required sector specific CO_{2e} charge in transport sector for making the NAP of the gasification-based systems positive. The left staple in each pair represents the 450 ppmv 2030 and the right staple is for 2040. The total required CO_{2e} charge is the sum of the sector general and the sector specific costs.

3.2 GHG EMISSION REDUCTION POTENTIAL

The GHG emission reduction potentials of the gasification-based systems calculated in this study are very similar to the GHG emission reduction potentials in the previous study (Holmgren, Berntsson et al. 2016). Only minor differences were found due to changes in marginal power production in some scenario points.

The comparative cases where the same amount of biomass is used in other processes than biofuel production via gasification all show comparatively high GHG emission reduction potentials. The two cases with electricity production and use in BEV show higher GHG emission reductions than the gasification-based systems (also those with CCS). The case with industrial bio-CHP show even higher GHG emission reductions than the case of directly replacing coal. The main reason for these high reduction potentials is the high efficiency of the BEV.

4 DISCUSSION/CONCLUSION

The results for this study show that the additional required sector specific CO_{2e}-charge needed in the transport for making gasification-based biofuel production systems profitable in the future is not higher than the current level of transport fuel tax in Sweden. As comparison, the Swedish fuel tax level is of similar magnitude as in several other European countries (e.g. the Netherlands, Germany, Finland, Norway, Switzerland etc.) (OECD 2017; Santos 2017).

The conventional bio-CHP systems resulted in higher profitabilities than the gasification based systems, but also had a higher dependency on heat sinks and high prices of heat.

A very important limitation in the present study is that the GHG emissions associated with the production of the vehicles, batteries and other infrastructure (industrial, filling stations etc.) are not included.

The GHG emission reduction calculations and the comparison to the other biomass-based systems with conventional conversion technology and new vehicles (battery electric vehicles) showed that if not including the battery production, the vehicle production and infrastructure, the production of electricity and use in the transport sector seemed to have a larger potential for GHG reductions.

It should be noted, that available LCA studies including well to wheel emissions and battery production (studies e.g. (Nordelöf, Messagie et al. 2014, Ager-Wick Ellingsen, Singh et al. 2016) show that the carbon intensity of the electricity production, both for the battery production and for the electricity in the use phase of the BEV, has significant impact on the GHG performance. For well-to wheel systems based on wind-based electricity production the LCA GHG emissions are very low (Nordelöf, Messagie et al. 2014).

The investigated route with bio-CHP and use of electricity for BEV gave higher GHG emission reductions. Also in this context, the bio-CHP system showed a higher dependency on heat sinks.

Future studies of the use of biofuels and biomass for the transport sector should also consider other ways of producing the electricity (wind, solar, etc.), the impact of electrification of the transport sector on the power sector, and other sectors with less alternatives of replacing fossil sources.

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