CLIMATE PERFORMANCE OF BIOFUELS

- PRODUCED FROM FOREST RESIDUE HARVESTED IN SWEDEN

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Summary

Biofuels produced from forest residues are much discussed in a Swedish context, among other things due to concerns for climate change. However, the undertaking of climate performance calculations is not an exact science. To examine whether climate concerns may be met by biofuels produced from forest residues, a literature review was carried out, analysing studies across methodologies.

The scope for the literature review was limited to climate performance calculations for biofuels produced from forest residues harvested in Sweden. Five articles have been chosen for presentation, whereof one was carried out according to ISO 14040:2006 methodology, two according to climate performance calculations as stipulated by RED, two according to cumulative radiative forcing (CRF) and one according to a bottom up model using data from demo plants in Sweden (one study covers both ISO and RED methodology). All five studies presented in this paper suggest that climate performance of biofuels produced from forest residue (harvested in Sweden) show significantly better climate performance than fossil fuels.

The local, environmental effects as well as future potential for harvesting of forest residue were also explored. A synthesis report on local, environmental effects suggests that the local, environmental effects are small. Furthermore, it is concludes that the effects on SOC are minor. Lastly, it is suggested that there is potential of increased harvesting of forest residue in Sweden in the magnitude of 30 TWh.

Sammanfattning

Biobränslen producerade av skogsavfall diskuteras mycket i en svensk kontext. Eftersom beräkningar av klimatprestanda inte är en exakt vetenskap, utfördes en litteraturstudie för att undersöka utifall biobränslen producerade från skogsavfall kan uppfylla förväntad klimatprestanda.

Litteraturstudien avgränsades till beräkningar av klimatprestanda för biobränslen producerade av svenskt skogsavfall. Fem artiklar valdes ut, varav en använde sig av ISO 14040:2006 metodologi, två utfördes enligt RED, två enligt strålningsberäkningar och slutligen en som använt sig av data från demo fabriker i Sverige. Alla fem studierna visar att biobränslen producerade från svenskt skogsavfall har signifikant bättre klimatprestanda i jämförelse med fossila bränslen.

De lokala miljömässiga effekterna samt framtida potential undersöktes. En syntesrapport drog slutsatsen att de lokala miljömässiga effekterna var små. Vidare, drogs slutsatsen i en annan rapport att effekterna på kol i marken var små. Slutligen uppskattades den framtida öka potentialen av ett ökat uttag av skogsbränsle till ca 30TWh per år.

Table of content

1. Background

The concept of bioeconomy is gaining policy ground within the EU (European Union 2016), as well as among the Nordic countries and within the Baltic Sea Region (Nordic Council of Ministers 2016). According to OECD a bioeconomy is; *"from a broad economic perspective, /…/ the set of economic activities relating to the invention, development, production and use of biological products and processes"* (OECD 2009). In short, it might be explained as activities creating value from (sustainably managed) biomass, in contrast to value created from a fossil driven economy.

Biofuels are often mentioned as a part of the bioeconomy and policy measures have historically been taken and are presently taken to support the production. This is partly motivated by climate change arguments, and partly by possible contribution to security of energy supply and economic activity. Recently, however, policy framework supporting biofuels on a European level has been changed due to sustainability concerns (i.e. the Renewable Energy directive within the European Union).

The changes, voted upon in the European Parliament during spring 2015, were heatedly debated. The scientific community is not unified and there is also a divide among policy makers. The biofuel industry has been reporting uncertainty regarding taking decisions on investments during the period of debate, consequently causing stalled investments (The European Biomass Association 2015) (European Biomass Industry Association 2015).

The new rules aim to promote advanced biofuels[1] (The European Parliament and the Council of the European Union 2015). It might be discussed how effective the policy framework is, but it is clear that advanced biofuels are favoured over conventional biofuels (The European Parliament and the Council of the European Union 2015).

In a Swedish context, using forest residue (branches, tops and stumps) for production of advanced biofuels is much discussed. Research wise, to the knowledge of the author, there is no comprehensive literature review conducted specifically for biofuels produced from Swedish forest residue. Therefore, in line with policy development on a European level, a literature review of current studies on biofuels produced from Swedish forest residue was conducted, in order to contribute to the current level of knowledge. The focus of the literature review was climate performance calculations, but also looked into other sustainability aspects as well as future potential.

[1] IEA defines advanced biofuels accordingly; *"Advanced biofuel technologies are conversion technologies which are still in the research and development (R&D), pilot or demonstration phase, commonly referred to as second- or third- generation."* (International Energy Agency 2016)

2. Goal

The goal of this paper is to identify state of the art knowledge regarding climate performance for biofuels produced from forest residues in Sweden. Although climate performance is a key element of sustainability for biofuels, other aspects are also of importance to achieve sustainability in all three categories (e.g. environmental, economic and social). Therefore, this paper also aims at giving an introduction to some existing sustainability frameworks for biofuels. In order to exemplify the environmental dimension, state of the art regarding local environmental effects of increasing harvesting of forest residues are presented. Lastly, future potential for biofuels produced from Swedish forest residue is touched upon due to questions of viability and scale.

3. Methodology and limitations

A literature review was carried out by means of database search. The search engines Web of science, Scopus, GreenFILE (EBSCO), worldwideenergy.org, Libris and Primo were used. Important keywords were; biofuel, bioenergy, lignocellulosic, forest residue, slash, sustainability, LCA, life cycle assessment, Sweden, second generation and advanced. Their Swedish counterparts were also used.

The scope was limited to studies assessing climate performance of biofuels produced from forest residues harvested in Sweden. The studies therefore had to fulfil at least two criteria:

- using data of Swedish forest residues
- perform climate performance calculations were the results were presented in such a way that it could be distinguished what conclusions held for biofuels produced from Swedish forest residues (and what conclusions held for other feedstock)

Furthermore a historic limit was chosen. Since there is a rapid development within the field, studies published before 2010 were omitted.

The five studies presented in the result section were chosen with regards to calculation methods and the two criteria mentioned above. The chosen studies represent the 3 most common ways of assessing climate performance for biofuels as well as one alternative bottom-up method. The data sets are also different. The material was then used to identify how biofuel produced from forest residue compares to fossil fuels regarding climate performance.

The chapter on sustainability of biofuels was limited to introducing the global debate on the scramble for biomass, the different production chains and the European Union framework for sustainability of biofuels as well as the framework developed by *The Roundtable on Sustainable Biomaterials*. The EU framework for sustainability of biofuels was chosen since it is legislatively of great importance for Sweden. In order to give a point of reference, the criteria system developed by the international stakeholder organisation *The Roundtable on Sustainable Biomaterials* is mentioned.

The material presented regarding local and environmental effects of an increased harvesting of forest residues was limited to the literature review conducted by the Swedish Energy Agency in 2013. Since effects on soil organic carbon (SOC) was not part of the literature review one complementary study was presented giving some insight in the changes of SOC.

The material presented on future potential was limited to the literature review carried out by Börjesson et al. 2013, since they conducted a thorough examination of state of the art.

4. Sustainability of biofuels

Bioenergy presents a large potential and opportunity. It may contribute to mitigating climate change, increase energy security and economic activity, but in order to not compromise other values (e.g. human and environmental well-being), there is a need for harvesting, production and distribution to be done sustainably. Although this paper mainly focuses on climate performance, introductions to the global debate on the scramble for biomass (credits KTH prof. em. Staffan Laestadius for the concept-name), the different production chains as well as existing sustainability frameworks for biofuels are given, in order to give context and broaden the view on sustainability of biofuels.

4.1 The scramble for biomass

The technical know-how on how to replace GHG intensive products by products produced from biomass is increasing. E.g. multi-story buildings traditionally requiring great amounts of GHG emitting cement, may now be produced from processed wood (se e.g. Byggvärlden 2012). Biomass may also be used to produce biofuels, furniture, paper, packaging, fibres for clothes etc. Due to the many field of applications, the question whether existing biomass suffices to satisfy future demand in all categories have been raised, globally as well as locally (Slade et al. 2014). The International Renewable Energy Agency (IRENA) looked into global use per sector in 2014 and concluded that 62% of the biomass used in 2010 was used for residential and commercial purposes, 15% for industry, 9% for transport, 8% for power and district heating and power, the last 6% comprise of mixed end uses. (International Renewable Energy Agency (IRENA) 2014). During the same year, 2010, the global demand for traditional biomass[2] was approximately 31.44 EJ.[3] However, estimates of untapped potential of sustainably managed biomass on a global scale varies a lot and comprise uncertainties to an extent which possibly makes it hard to provide policy guidance (Slade et al. 2014).

[2] As defined by IEA 2012; *"Traditional biomass comprises wood, charcoal, crop residues and animal dung mainly used for heating and cooking"* (IEA 2012).

[3] This could be compared to world wide oil demand of 187.62 EJ in 2010 (IEA 2010).
Calculated from IEA world energy outlook 2010, given 84.0 mb/d (million barrels per day). Assumed that 1 barrel of oil equivalent = 5.80 MBtu and that 1 MBtu = 1055.05585 MJ.

4.2 Production chains – from biomass to fuel

Climate performance of any given biofuel is much dependent on the design of the production chain, that is, the process from biomass to the refined fuel. The following section provides an introduction to the various processes, but due to scope restrictions, the climate performance of each production chain has not been studied. An introduction is given to enhance the understanding of complexity.

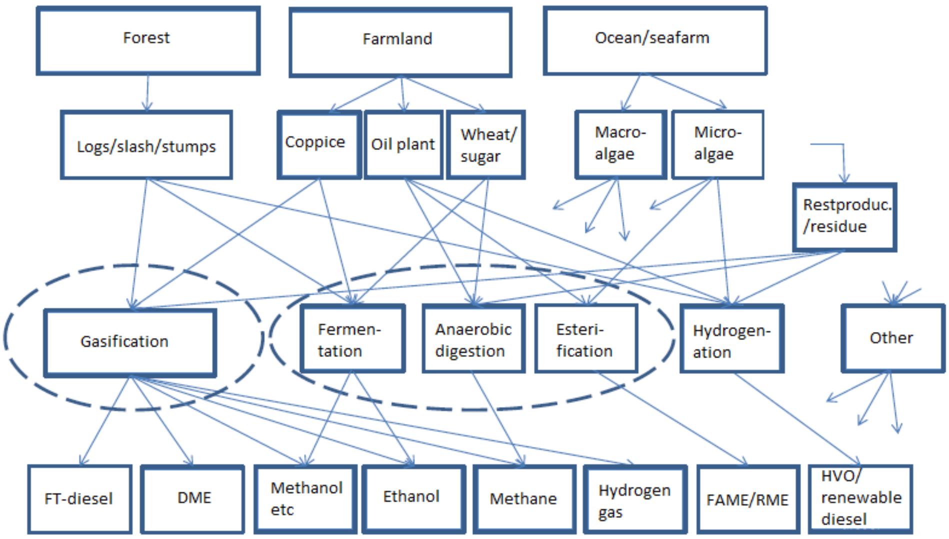

Figure source: (Börjesson et al. 2013)

Figure 1 – Overview of production chains

When studying production chains one may do so from different perspectives. Depending on the aim of the study it may be of interest to follow a specific feed (e.g. forest residue) or it may be of interest to study the different refining processes (e.g. gasification) or, lastly, it might be of interest to study production chains for a specific fuel (e.g. ethanol). Figure above aims at providing an understanding of how complex the systems may be. For example, following forest residue (logs/slash/stumps), it may be noted that at least three processes (gasification, fermentation and hydrogenation) may be applied when refining. In turn, these three refining techniques have the capability of producing at least 7 different types of fuel. Given the complexity of the system and the many production chains, it is hence not possible to say anything exact about any given category of biofuel, each production chain needs to be considered individually to establish specific climate performance.

4.3 Sustainability frameworks for biofuels

Sustainability is a holistic term, often described as having three dimensions; economic, social and environmental. Therefore, frameworks of sustainability for biofuels ideally address all three dimensions, including climate performance and other elements.

Several institutions have set up frameworks in order to ensure that minimum levels of sustainability are achieved. From a Swedish perspective, the EU criteria are legislatively among the most important. However, it might be argued that there are aspects lacking in the EU framework. Therefore, a criteria system developed by the international stakeholder organisation *The Roundtable on Sustainable Biomaterials* is presented as a point of reference. Both systems are described briefly below. Further information on the Renewable Energy Directive that governs the EU criteria follows in the next chapter.

4.3.1 EU criteria for biofuels

The European Union has adopted a set of sustainability criteria for biofuels. As of now, they are focused on greenhouse gas emissions, land with a high biodiversity value, land with high carbon stock and land use change (European Commission 2010). Carbon emissions initially needed to be reduced by at least 35% in comparison to fossil fuels. From the 5th of October 2015 all plants commissioned need to fulfil a 60% reduction. (The European Parliament and the Council of the European Union 2015)

Land with a high biodiversity value is defined as:

" ● primary forest and other wooded land /…/

● areas designated by law or by the relevant competent authority for nature protection purposes; or for the protection of rare, threatened or endangered ecosystems or species /../

● highly biodiverse grassland /…/ " (European Parliament 2009)

and may not be used for biofuel production.

Land with high carbon stock is defined as:

" ● wetlands /…/

● continuously forested areas /…/

● land spanning more than one hectare with trees higher than five metres and a canopy cover of between 10 % and 30 %, or trees able to reach those thresholds in situ /…/" (European Parliament 2009)

and may not be used for biofuel production.

Indirect land use change is a recently introduced concept in EU legislation, voted on in 2015 (The European Parliament and the Council of the European Union 2015). In short, it may be explained as aiming at smoothening the economic and climate effects caused by increased demand of agricultural land and the effect on food prices due to biofuel production. The introduction of indirect land use change in the EU legislation has been much debated. It will be explained more in depth in the following chapter.

4.3.2 Roundtable on Sustainable Biomaterials

The international stakeholder organisation *The Roundtable on Sustainable Biomaterials* have developed a set of criteria and indicators in order to ensure the sustainability of biomaterials (The Roundtable on Sustainable Biomaterials 2011). Each criteria and related indicator fall under a principle, which are divided into two categories; environmental & technical principles and social & institutional principles. The environmental and technical aspects include the following principles; greenhouse gas emissions, conservation, soil, water, air, use of technology, input and management of waste. The social and institutional includes; legality, land rights, local food security, rural and social development, human and labour rights, planning, monitoring and continuous improvement.

5. Existing framework for climate performance calculations

There are a variety of ways to calculate climate performance for biofuels. However, there are three types of methods that stand out as most commonly used; LCA according to the ISO 14000 framework, LCA according to the EU Renewable Energy Directive (also called the RE Directive or RED) and lastly, in the case of analysing climate performance with regards to forest residue, radiative forcing. Here follow accounts of the different methods.

5.1 ISO 14000 LCA

ISO is an acronym and stands for the International Organisation of Standardisation. The organisation was founded in 1947 and head quarter is located in Geneva, Switzerland (ISO 2016). Today it gathers 161 national standards bodies (ISO 2016). ISO has developed a broadly used framework for environmental management systems called ISO 14000. Within the framework there is a subcategory for life cycle analysis which is called 14040:2006, where 2006 indicates that it was published in 2006. Even more specifically, in 2015 a framework for sustainability criteria for biofuels was developed, called ISO 13065:2015. However, the studies presented in the literature review below were published before 2015 and have used the 14040:2006 framework for their calculations.

The framework for LCA 14040:2006 is not an exact methodology (Technical Committee ISO/TC 207 2006). It is an iterative process, where the outcome is presented in relative terms. The technique follows four steps; goal and scope definition, inventory analysis, impact assessment and interpretation.

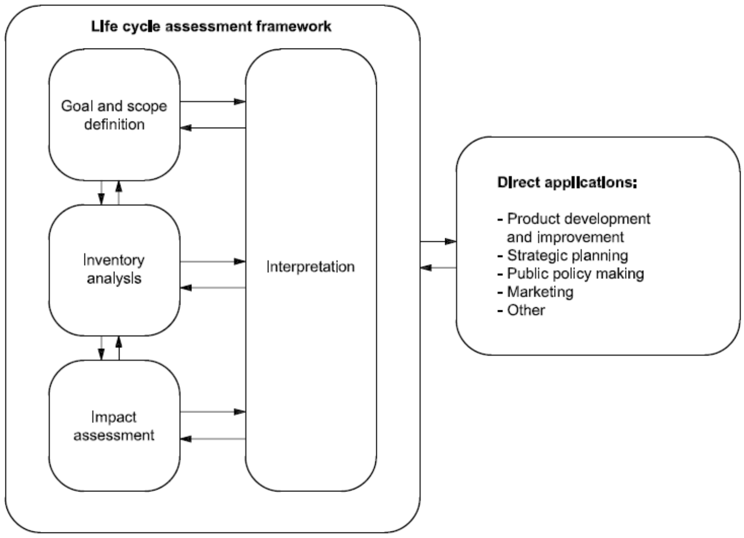

Figure source: (Technical Committee ISO/TC 207 2006)
Figure 2 – Life cycle assessment framework

In phase 1 goal and scope is defined, e.g. level of detail and system boundaries are clarified. Phase 2 consist of a life cycle inventory analysis, that is, collecting data and clarifying input and output variables. Phase 3 consists of a life cycle impact assessment, meaning additional information is processed, building upon the results in phase 2 in order to clarify environmental impact. In phase four, an interpretation of the results is made and recommendations may be given, e.g. for policy makers, product development, marketing etc. Even though the final result from a LCA is the interpretation, it is of interest to note that a functional unit is chosen for the calculations, representing a relative result. The ISO framework for sustainability of biofuels published in 2015 (ISO 13065:2015) is specified to a greater extent.

5.2 EU Renewable Energy Directive (RE directive/RED)

In order to understand the calculation methodology stipulated by RED, it is of value to be aware of the policy context. Therefore, the RE directive and the recent changes are presented below. The concept of indirect land use change is explained for the same reason. iLUC is of further importance since it concretely might change the EU methodology for climate performance calculations for biofuels in the near future. How iLUC will be taken into account with regards to climate performance calculations for biofuels produced from forest residue is yet to be decided.

5.2.1 Content of the directive

The EU Renewable Energy Directive (also called the RE Directive or RED), was adopted in March 2009. The purpose of the directive is to promote the use of renewable energy in the member states. The directive requires member states to submit national renewable energy plans as well as report on progress. It further specifies how calculations in order to meet the requirements should be carried out (European Parliament 2009).

In April 2015, the EU parliament adopted amendments to the 2009 directive (The European Parliament and the Council of the European Union 2015). The changes to the previous directive may be summarized as follows:

1. in both the 2009 and 2015 directive a 10% target for renewable fuels in the transport sector by 2020 is adopted, although in the 2015 directive there is a 7% cap for conventional biofuels[4]. That is, no more than 7% of conventional biofuel may be counted towards each member states 10% target.
2. there is an optional target of 0,5% for advanced biofuels[5]. That is, member states are recommended to set a 0,5% target for advanced biofuels.
3. biofuels produced from certain biomass are eligible for double counting, meaning that they count towards the target times a factor two, twice their energy content. For the full list, see appendix 1.

These changes aim towards promoting advanced biofuels. The commission will evaluate how effective the measures have been by the 31 December 2017 (The European Parliament and the Council of the European Union 2015). It is, however, of importance to understand how the changes above effect the incentives of the member states to incentivize the production, distribution and usage of biofuels.

Point 1 has implications with regards to new investments and the profitability of current investments. Since there is a cap of 7% for conventional biofuels, the incentive for member states to stimulate such investments and production decreases. Point 2 signifies an incentive for member states to stimulate advanced biofuels. Since it is optional, it is however not binding. Point 3 also signifies an incentive for member states to stimulate advanced biofuels. Since certain fuels are eligible for double counting, member states may potentially fulfil the targets of 10% renewable fuels in transport by half the energy content if the right sort of fuels are promoted.

[4] IEA defines conventional biofuels accordingly; "*Conventional biofuel technologies include well-established processes that are already producing biofuels on a commercial scale. These biofuels, commonly referred to as first-generation, include sugar- and starch-based ethanol, oil-crop based biodiesel and straight vegetable oil, as well as biogas derived through anaerobic digestion.*" (International Energy Agency 2016)

[5] IEA defines advanced biofuels accordingly; *"Advanced biofuel technologies are conversion technologies which are still in the research and development (R&D), pilot or demonstration phase, commonly referred to as second- or third- generation."* (International Energy Agency 2016)

5.2.2 Indirect land use change – iLUC

Divided opinions within the research community

One of the first scholars to introduce the concept of indirect land use change (iLUC) was Searchinger et al. In 2008, Searchinger et al. published an article in Science discussing indirect effects of using agricultural land for energy crops in order to produce biofuels (Searchinger et al. 2008). They modelled effects on land use change by using an (economic) partial equilibrium model (Searchinger et al. 2008). Very simplified, the dynamics of the model may be described as follows; as production of bioethanol is incentivized, the price of feedstock for bioethanol (e.g. maize) rises. Gradually, the economic rationale for growing maize increases and becomes an economically better option for farmers. It becomes attractive to divert land from the original use (e.g. soy bean and wheat production), to farming of energy crops. This, in turn, effects prices of soy bean and wheat, which effects land use and so on. In their model, it is assumed that increased maize, soy bean and wheat leads to deforestation, which leads to increased GHG emissions. The study concluded that ethanol produced from maize doubled GHG over a period of 30 years, radically changing the calculations of climate performance for such a fuel (Searchinger et al. 2008).

The study spurred debate among scientist as well as policy makers. Other scholars followed up with similar studies and the conclusions ranged from being similar to Searchinger et alt. to showing opposite results (Ahlén & Bryngelsson 2009). Some of the critique was summarised by Ahlén & Bryngelsson 2009 and follows here:

" ● a partial equilibrium model cannot catch all the relevant dynamics from such a complex system /../ a general equilibrium model, taking supply and demand of agricultural products and land into account, must be used (instead) /…/

● the complexity behind deforestation commented on by (Kline 2008) where they emphasized that 'interactions among cultural, technological, biophysical, political, economic, and demographic forces within a spatial and temporal context rather than by a single crop market' should be taken into consideration in order to explain the dynamics. /…/

● using local data for LCA does not take time or scale effects into account, which can be very relevant for an upscaling of a large system over a long time. /…/

● trying to estimate secondary and tertiary effects on the global economy from such a small perturbation is nothing but speculations /…/ "

Methodologies to estimate iLUC

iLUC can only be estimated by means of modelling and is not possible to observe (E4tech; Ecofys; International Institute for applied system analysis; 2015). Models used to quantify and estimate iLUC are economic models, often models of the global agricultural market. There are mainly three applicable models:

- partial equilibrium models (see e.g. (E4tech; Ecofys; International Institute for applied system analysis; 2015))
- computational general equilibrium models (see e.g. (Brinkman et al. 2015)) and
- agent based models (see e.g. (Ahlén & Bryngelsson 2009))

Effects on RED

As of today (May 2016), no major changes have been made to the climate performance calculations for biofuels within RED with regards to iLUC. Instead, the commission was mandated to produce a report with regards to state of the art within sustainability of biofuels (economic, social and environmental factors included) and submit to the European Parliament and the council no later than 31st of December 2016 (The European Parliament and the Council of the European Union 2015). This report may, if appropriate, be accompanied by suggestions for policy measures. Thus it is still unclear how climate performance calculations will be affected by the European Parliament's decision to include iLUC in climate performance calculations for biofuels.

5.2.3 Calculation methodology

The RE Directive also specifies how to perform GHG emission calculations. The following formula is used:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{eccs} - e_{eccr} - e_{ee}$$

gCO2eq/MJ (CO2 equivalent per MJ of fuel)

where

E = total emissions from the use of the fuel;
e_{ec} = emissions from the extraction or cultivation of raw materials;
e_l = annualised emissions from carbon stock changes caused by land-use change;
e_p = emissions from processing;
e_{td} = emissions from transport and distribution;
e_u = emissions from the fuel in use;
e_{sca} = emission saving from soil carbon accumulation via improved agricultural management;
e_{ccs} = emission saving from carbon capture and geological storage;
e_{ccr} = emission saving from carbon capture and replacement; and
e_{ee} = emission saving from excess electricity from cogeneration.

Equation 1

Emissions from the manufacture of machinery and equipment are not taken into account. The formula specifying how e_l is defined may be found in appendix 2. Economic operators, who are obliged to report on this data, may choose to use default values that are provided in RED or they may choose to calculate actual performance based on real data.

When calculating the climate performance for biofuels produced from forest residues, it is assumed that the GHG emissions from the act of combustion is equal to zero (Westerberg 2016). Furthermore, since forest residues are defined as byproducts, the GHG emissions due to logging and harvesting are not taken into account (Westerberg 2016), which means that the first emissions counted towards climate performance occurs when the material is transported from the site. The climate performance calculations then follow the whole chain, from transportation to refining and further on to distribution. The chain stops when the fuel is delivered for use. This means that no time frame is taken into account.

5.3 Radiative forcing

Radiative forcing may be explained as the correlation between radiation absorbed by the surface of the earth as well as the atmosphere and the global mean equilibrium temperature. IPCC, the Intergovernmental Panel on Climate Change, uses the definition laid out by Ramaswamy et al. 2001; *"the change in net (down minus up) irradiance (solar plus longwave; in W/m^2) at the tropopause after allowing for stratospheric temperatures to readjust to radiative equilibrium, but with surface and tropospheric temperatures and state held fixed at the unperturbed values"* (IPCC 2007). Mathematically the radiative forcing (RF) is related to the global mean equilibrium temperature by a linear relationship according to the following formula:

$$\Delta T_s = \lambda RF$$

Equation 2

where λ is the climate sensitivity parameter and ΔT_s is the change in global mean temperature. Greenhouse gases absorb radiation, so when using radiative forcing theory for climate performance calculations, it is analysed how the global mean temperature change, due to increased emissions.

6. Results from literature review

Although the focus of the literature review was climate performance calculations, the aspects of local, environmental consequences of increased harvesting of forest residues, as well as potential for forest residues, are presented. The rationale of introducing the local, environmental effects of increased harvesting of forest residues is interlinked with the broader concept of sustainability presented in section 6. Presenting the current state of the art regarding the potential for increased harvesting of forest residues is motivated by the future feasibility of also increasing production of biofuels produced from forest residue.

6.1 Climate performance calculations

As mentioned when describing the limitations in chapter 3, the scope for this literature review covers biofuels produced from forest residues harvested in Sweden. Five articles fulfilled the selectivity criteria, whereof one was carried out according to ISO 14040:2006 methodology, two according to climate performance calculations as stipulated by RED, two according to cumulative radiative forcing (CRF) and one according to a bottom up model using data from demo plants in Sweden (one study covers both ISO and RED methodology). The results from the literature review is presented in table 1-5 below.

6.1.1 Results from literature review on climate performance calculations

Table 1: Dagens och framtidens hållbara biodrivmedel *(freely translated: Biofuels of today and in the future)*

Author, institution, year	Börjesson, P.; Lundgren, J.; Ahlgren, S.; Nyström, I. f3 – The Swedish knowledge centre for renewable transportation fuels 2013
Type of analysis	Climate performance calculations according to RED.
Type of fuel	SNG, methanol, DME, FT-diesel, hydrogen gas by gasification.
Land use change	Land use change was taken into account according to ISO and RED standards that were applicable during the time the study was carried out. iLUC was not considered.
Time span	Not spec.
Baseline used for comparison	84 g CO_2 eq per MJ for gasoline and diesel.
Summarized conclusions	When tops and branches are used as feedstock, a greenhouse gas reduction of 92-95% compared to fossil fuels is achieved.

Table 2: Ethanol production in biorefineries using lignocellulosic feedstock
- GHG performance, energy balance and implications of life cycle calculation methodology

Author, institution, year	Karlsson, H.; Börjesson, P; Hansson, PA.; Ahlgren, S.; Swedish University of Agricultural Sciences Lund University 2014
Type of analysis	LCA according to ISO standard and climate performance calculations according to RED. Well-to-tank.
Type of fuel	Ethanol from forest residue.
Land use change	Land use change was taken into account according to ISO and RED standards that were applicable during the time the study was carried out. iLUC was not considered.
Time span	Not spec.
Baseline used for comparison	Method I (ISO) uses 89.2 CO_2 eq per MJ for diesel and 87.6 CO_2 eq per MJ for petrol. In Method II (RED), values of 83.8 g CO_2 eq per MJ for all fossil fuels were used.
Summarized conclusions	13.84 CO_2 eq per MJ for ethanol produced from forest residue using method I (ISO), meaning a GHG emission reduction of approximately 84% compared to diesel and petrol. 14.86 CO_2 eq per MJ for ethanol produced from forest residue using method II (RED), meaning a GHG emission reduction of approximately 82%.

Table 3: The time aspect of bioenergy – climate impacts of solid biofuels due to carbon dynamics

Author, institution, year	Zetterberg, L.; Chen, D. IVL, Swedish Environmental Research Institute University of Gothenburg 2015
Type of analysis	Radiative forcing (RF) as an indicator of climate impact.
Type of fuel	Not spec.
Land use change	Land use change (direct and indirect) is not applicable to the chosen method of calculation.
Time span	20 years and 100 years
Baseline used for comparison	70 g CO_2 eq per MJ for gas 105 g CO_2 eq per MJ for coal
Summarized conclusions	Climate impacts from using forest residues and stumps depend on the decomposition rates and the time perspective over which the analysis is done. Over a 100-year perspective, branches and tops have lower climate impacts than stumps, which in turn have lower impacts than fossil gas and coal. Over a 20-year time perspective, branches and tops have lower climate impacts than all other fuels but the relative difference is smaller. Stumps have slightly higher climate impacts over 20 years than fossil gas but lower impacts than coal.

Table 4: Time-dependent climate benefits of using forest residues to substitute fossil fuels

Author, institution, year	Sathre, R.; Gustavsson, L. Mid Sweden University Linnaeus University 2011
Type of analysis	Cumulative radiative forcing (CRF) as an indicator of climate impact.
Type of fuel	Not spec.
Land use change	Land use change (direct or indirect) is not applicable to the chosen method of calculation.
Time span	240 years
Baseline used for comparison	Coal, oil and fossil gas. Emissions per MJ of fuel unspecified.
Summarized conclusions	Over a 240-year period, CRF is significantly reduced when forest residues are used instead of fossil fuels. The type of fossil fuel replaced is important, with coal replacement giving the greatest CRF reduction.

Table 5: The climate benefit of Swedish ethanol: present and prospective performance

Author, institution, year	Börjesson, P.; Ahlgren, S.; Berndes, G. Lund University Chalmers University of Technology 2012
Type of analysis	The calculations are based on data from demo plants and modelling of ethanol plants that are considered to be technically and economically viable. Data for demo plants taken from (Sassner & Zacchi 2008).
Type of fuel	Ethanol from forest residue.
Land use change	iLUC was not considered.
Time span	30 years
Baseline used for comparison	Approximately 80 g CO_2-equivalents per MJ
Summarized conclusions	Excluding direct land use change: when system expansion is applied, the net emissions range from roughly zero to slightly below 20 g CO2-equivalents per MJ ethanol, equivalent to more than a 75% GHG reduction compared with fossil vehicle fuels. Including direct land use change: 10.0 g CO2-equivalents per MJ when system expansion is applied, meaning a GHG emission reduction of approximately 88%.

It may be noted that biofuels produced from forest residues harvested in Sweden, show a considerably higher climate performance in all five studies when compared to fossil fuels. Using ISO and RED methodology, the performance range from an 82 – 95 % reduction of GHG emissions. The results from the study conducted by Sathre & Gustavsson 2011 are presented in the unit (*Ws/m^2)/ha*, were a reduction of approximately 0.88 (*Ws/m^2)/ha* for slash replacing coal when using traditional forest management is observed. The results from the study conducted by Zetterberg & Chen 2015 are presented in the unit *Mt CO_2 eq. per 1 PJ of fuel and year*, were coal represent approximately 12.5 Mt CO_2 eq. per 1 PJ of fuel and year and branches and tops approximately 2 Mt CO_2 eq. per 1 PJ of fuel and year, consequently representing an approximate reduction of 84%. Börjesson et al. 2012 present reductions of GHG emissions ranging from 75 – 88 %.

When going through the studies, two factors have been identified as extra important for the result (when conducting climate performance calculations for biofuels produced from forest residues harvested in Sweden):
- the time scale
- what type of fossil fuel constitutes the baseline
Since climate performance calculations are often presented in percent (compared to fossil fuels and on a given timescale), the comparative factors are of great importance.

The time aspect is particularly important for climate performance calculations for forest residues. If the residues are not harvested, they are left in the woods to decay, which results in carbon emissions. The emissions span over a greater period of time, but are still emitted. Zetterberg and Chen 2015 draw the conclusion that in an initial phase (about 20 years), fuel produced from forest residues will have a larger climate impact than gas, but over a period of 100 years, this changes (Zetterberg & Chen 2015).

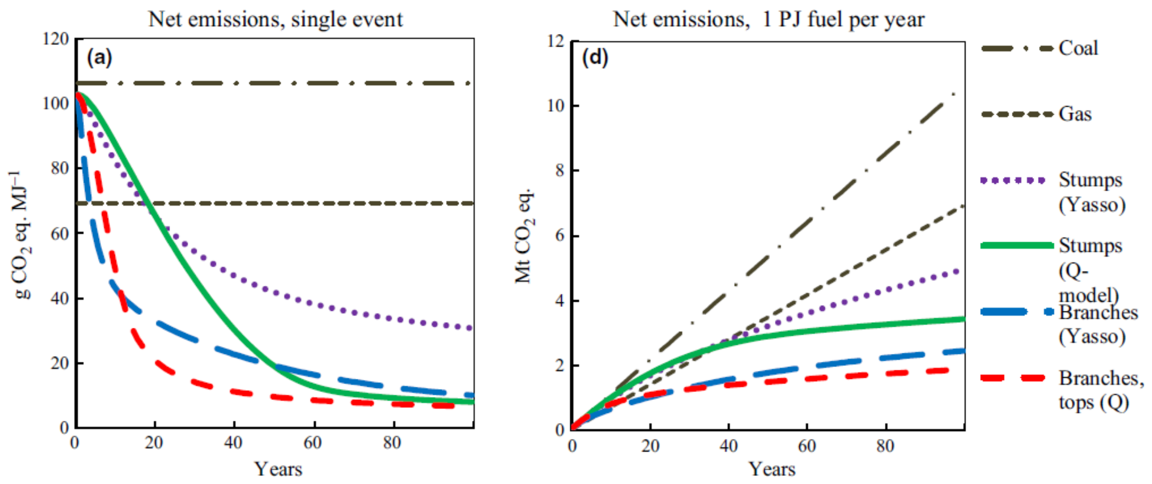

Figure source: (Zetterberg & Chen 2015)

Figure 3 – Net emissions for single event and 1PJ fuel per year

It is also of importance to notice that the type of fossil fuel chosen as a baseline for comparison is of significance. As may be seen from figure 3, the climate performance of biofuels produced from forest residues harvested in Sweden changes if compared to coal or gas respectively, since the carbon intensity varies.

One of the initial research questions for this paper regarded whether any pattern could be seen concerning if a certain methodology enhances or discredits biofuels produced from forest residues harvested in Sweden. This remains inconclusive, due to the number of studies found, but it is however still interesting to note that none of the presented studies indicates that it would be the case.

It may also be noted that none of the studies take iLUC into account. Since the EU framework for iLUC is not yet finalized and no study has elaborated with the potential effects of iLUC for climate performance results (for biofuels produced from forest residues harvested in Sweden), it is not possible to draw any conclusion on how the iLUC framework might influence the climate performance calculations. It might however be noted that forest residues currently appear on the list of feedstock in RED (see appendix 1) that are eligible for double counting, which indicates that biofuels produced from forest residues are currently supported by the EU.

6.2 Local, environmental consequences of increased harvest of forest residue

Harvesting forest residue is associated with local environmental effects. A synthesis report was published by the Swedish Energy Agency in 2013, going through state of the art for eutrophication, acidification, toxins and biodiversity. Regarding the harvesting of tops and branches, Jong & Stedingk 2013 concludes that the effects are small in all categories (Jong & Stedingk 2013). It is also stated that increased harvesting is possible. Regarding stumps, it is stated that an increased harvesting of stumps may effect biodiversity, since stumps serve as biotopes for certain species (Jong & Stedingk 2013). However, the Swedish forest agency provide guidelines for the harvesting of stumps, which enables foresters to maintain biodiversity and take out around 75-85 % of the stumps (Swedish Forest Agency 2009).

Another aspect of harvesting forest residue concerns soil organic carbon (SOC). It has been questioned whether removal of forest residues may decrease SOC. State of the art indicate that this is the case during an initial period of time, but changes over a longer time scope. For example Hyvönen et alt. concludes; *"most of the decline in soil C stocks after harvesting of logging residues* *was offset by the litter production of the following forest stands by the time of first thinning in the low productive stands, while in the high productive stands slightly lower stores were observed during the entire rotation period, given that no decline in biomass production has occurred"* (Hyvönen et al. 2012). This indicates that during a longer time scope, the variations are marginal.

6.3 Future potential

The potential for increasing the harvest of forest residues have been estimated by many actors. Börjesson et al. carried out a literature review in 2013 on behalf of the Swedish Energy Agency and f3 – The Swedish knowledge centre for renewable transportation fuels. They went through literature which has examined the theoretical, technical, economic and environmental potential. After having considered different literature and all four perspectives, their summarized conclusion amounted to an increase of 30 TWh per year in order to keep long-term sustainability, given that logging remains constant (Börjesson et al. 2013).

7. Discussion

7.1 Comments on the result from the literature review

7.1.1 Validity of results

When carrying out the literature review in chapter 6, five studies were found that fulfilled the criteria laid out in the methodology and limitation section. However, it is interesting to note that there are other studies similar to the studies above, which did not fulfil some of the criteria (e.g. studying biofuel systems or using Swedish data) that point in the same direction. For example, Hammar et al. 2015 studied the use of logging residues for district heating in their study *"Time-Dynamic Effects on the Global Temperature When Harvesting Logging Residues for Bioenergy"*. They conclude that replacing coal with logging residue would give immediate climate benefit (Hammar et al. 2015). Furthermore, Koponen et alt. 2013 looked at the probability for different liquid biofuels to fulfil the climate performance requirements according to RED methodology. FT-diesel produced from (Finnish) forest residue is predicted to achieve approximately an 80% reduction of GHG emissions in comparison to fossil fuels (Koponen et al. 2013).

7.1.2 Comments on the practicability of using forest residue for biofuels

The synthesis report on local, environmental effects by Jong & Stedingk 2013 suggest that the local, environmental effects are small. Furthermore, Hyvönen et alt. 2013 concludes that the effects on SOC are minor. The report by Börjesson et alt. 2013 suggest that there is potential of increased harvesting of forest residue in the magnitude of 30 TWh and all studies found suggest that climate performance of biofuels produced from forest residue (harvested in Sweden) show significantly better climate performance than fossil fuels. It may also be noted that forest residues are harvested already today, although not on the suggested scale. Altogether, one might deduct that three important parameters (local, environmental impact, climate performance and future potential) seem to be in place, potentially making it a viable advanced biofuel in a Swedish context.

However, this paper has not taken technical or economical aspects into consideration (due to scope limitations). Whether production is viable, is of course very dependent on the profitability, where policy framework plays a big part. It may also be suggested that social aspects are taken into account (such as recreational value of forests) when assessing the production chain, in order to achieve sustainability in all three dimensions (environmental, economical and social).

7.2 The nature of climate performance calculations

As stated in chapter 5 (methodologies for climate performance calculations), there is a variety of ways to perform the calculations. Narrowing the scope to the most commonly used methodologies (ISO, RED and radiative forcing), they still represent a great variation. Furthermore, within each methodology, the line of reasoning and calculation may look very differently, one main factor being what assumptions are made, e.g. timeframe and baseline for comparison.

It might be argued that the undertaking of climate performance calculations is not an exact science. The LCA framework is very much under development and as described above, the RED methodology is about to change. The assumptions made and the specific applications (e.g. using cumulative radiative forcing or not) within the methodology is of importance to the result.

However, saying that the undertaking of climate performance calculations is not an exact science is not the same as discrediting the methodologies, but it should be noted that the calculations may be very effected by what assumptions are made. Hence, the outcome of the calculations by certain sets of assumptions.

7.3 Comments regarding iLUC

Since the exact changes to the RED methodology with regards to iLUC are still unknown, it is only possible to speculate on how the changes will effect climate performance calculations for biofuels produced from forest residues. It is however possible to go back to the definition of iLUC and look for probable outcome.

Indirect land use change occurs, according to the definition, when prices of agricultural commodities increase due to incentivized production of energy crops. What, if any, is the correlation between prices of agricultural commodities, land use change and forest residue? Since the area used for "production" of forest residue, is already allocated for forestry and in often unsuitable for food production, the correlation between prices of agricultural commodities, land use change and forest residues can be said to be weak. It might be argued that certain competitive effects arise regarding what the forest residues are used for (e.g. incineration vs. transport fuels), but this has little effect on the price of agricultural commodities. Based on this it might be questioned if forest residues will be attributed as being any large source of iLUC.

8. Conclusion

The five studies presented in this paper suggest that climate performance of biofuels produced from forest residue (harvested in Sweden) show significantly better climate performance than fossil fuels. The synthesis report on local, environmental effects by Jong & Stedingk 2013 suggest that the local, environmental effects are small. Furthermore, Hyvönen et alt. 2013 concludes that the effects on SOC are minor. Lastly, the report by Börjesson et al. 2013 suggest that there is potential of increased harvesting of forest residue in Sweden in the magnitude of 30 TWh. The effects of changes in RED due to iLUC remains inconclusive, but it might be argued that it is unlikely that forest residues will be attributed as being any large source of iLUC.

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Appendix 1

ANNEX IX Part A.

Feedstocks and fuels, the contribution of which towards the target referred to in the first subparagraph of Article 3(4) shall be considered to be twice their energy content:

(a) Algae if cultivated on land in ponds or photobioreactors.

(b) Biomass fraction of mixed municipal waste, but not separated household waste subject to recycling targets under point (a) of Article 11(2) of Directive 2008/98/EC.

(c) Bio-waste as defined in Article 3(4) of Directive 2008/98/EC from private households subject to separate collection as defined in Article 3(11) of that Directive.

(d) Biomass fraction of industrial waste not fit for use in the food or feed chain, including material from retail and wholesale and the agro-food and fish and aquaculture industry, and excluding feedstocks listed in part B of this Annex.

(e) Straw.

(f) Animal manure and sewage sludge.

(g) Palm oil mill effluent and empty palm fruit bunches.

(h) Tall oil pitch.

(i) Crude glycerine.

(j) Bagasse.

(k) Grape marcs and wine lees.

(l) Nut shells.

(m) Husks.

(n) Cobs cleaned of kernels of corn.

(o) Biomass fraction of wastes and residues from forestry and forest-based industries, i.e. bark, branches, pre- commercial thinnings, leaves, needles, tree tops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil.

(p) Other non-food cellulosic material as defined in point

(s) of the second paragraph of Article 2.

(q) Other ligno-cellulosic material as defined in point (r) of the second paragraph of Article 2 except saw logs and veneer logs.

(r) Renewable liquid and gaseous transport fuels of non-biological origin.

(s) Carbon capture and utilisation for transport purposes, if the energy source is renewable in accordance with point (a) of the second paragraph of Article 2.

(t) Bacteria, if the energy source is renewable in accordance with point (a) of the second paragraph of Article 2. Part B. Feedstocks, the contribution of which towards the target referred to in the first subparagraph of Article 3(4) shall be considered to be twice their energy content: (a) Used cooking oil. (b) Animal fats classified as categories 1 and 2 in accordance with Regulation (EC) No 1069/2009 of the European Parliament and of the Council (*)

(*)Regulation (EC) No 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No 1774/2002 (Animal by-products Regulation) (OJ L 300, 14.11.2009, p. 1).’.

(The European Parliament and the Council of the European Union 2015)

Appendix 2

7. Annualised emissions from carbon stock changes caused by land-use change, el, shall be calculated by dividing total emissions equally over 20 years. For the calculation of those emissions, the following rule shall be applied:

e_l = (CSR – CSA) × 3,664 × 1/20 × 1/P – e_B, (*)

where

e_l =annualised greenhouse gas emissions from carbon stock change due to land-use change (measured as mass (grams) of CO2-equivalent per unit of biofuel or bioliquid energy (megajoules)). “Cropland” (**) and “perennial cropland” (***) shall be regarded as one land use;

CSR =the carbon stock per unit area associated with the reference land-use (measured as mass (tonnes) of carbon per unit area, including both soil and vegetation). The reference land-use shall be the land-use in January 2008 or 20 years before the raw material was obtained, whichever was the later;

CSA =the carbon stock per unit area associated with the actual land-use (measured as mass (tonnes) of carbon per unit area, including both soil and vegetation). In cases where the carbon stock accumulates over more than one year, the value attributed to CSA shall be the estimated stock per unit area after 20 years or when the crop reaches maturity, whichever the earlier;

P =the productivity of the crop (measured as biofuel or bioliquid energy per unit area per year) and

e_B =bonus of 29 gCO2eq/MJ biofuel or bioliquid if biomass is obtained from restored degraded land under the conditions provided for in point 8.

(*)The quotient obtained by dividing the molecular weight of CO2 (44,010 g/mol) by the molecular weight of carbon (12,011 g/mol) is equal to 3,664.
(**)Cropland as defined by IPCC.
(***)Perennial crops are defined as multi-annual crops, the stem of which is usually not annually harvested such as short rotation coppice and oil palm.’

(The European Parliament and the Council of the European Union 2015)