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Abstract

Directive on the promotion of the use of energy from renewable sources in the European Union (EU), also called as RED, was published 5 June 2009 in the Official Journal of the EU (2009/28/EC). It establishes an overall binding target of a 20% share of renewable energy sources in the final energy consumption in the EU by 2020. In addition, a 10% binding minimum target for renewable energy sources in transport is set for each Member State. The RED also introduces environmental sustainability criteria for biofuels and other bioliquids. It states that the greenhouse gas (GHG) emission saving from the use of biofuels and other bioliquids taken into account for the national targets shall be at least 35% for current biofuels, at least 50% after 1 January 2017, and at least 60% after 1 January 2018 for biofuels produced in installations in which production started on or after 1 January 2017. The RED introduces a methodology to calculate the GHG emission savings of biofuels and other bioliquids compared to fossil fuels. In this report the methodology was tested with a case study based on commercial and industrial waste-derived bioethanol production integrated with a CHP plant in Finland. The aim of the report was to study whether the waste ethanol concept gains the 60% GHG emission savings according to the RED methodology or not.

Four different interpretations of the RED methodology were considered possible for the studied concept. All these options were calculated with three different process values depending on the need of sterilisation of the waste material and the amount of urea used in the process. Within these four options differences in the system boundary setting and thus allocation of emissions took place resulting in differences in emission saving results. The key question was, whether the CHP plant and the biofuel process were supposed to be treated as one combined process or as two separated ones. The GHG emission savings over

60% were gained when the biofuel process and the CHP plant were assumed to be separate processes and the amount of heat and urea needed in the process were minor. The GHG emission saving of the waste ethanol was highly dependent on the emission factor given for the waste material combusted at the CHP plant. The emission factor was the higher the higher were the plastic and moisture contents of the waste. To gain results with over 60% emission savings, attention should be paid to minimization of the plastic content of waste material combusted. Over 60% emission savings could also be gained if carbon capture and replacement or storage were applied for the biogenic carbon dioxide released from the ethanol processing (fermentation).

Preface

This report presents the main results of a study with the aim to calculate greenhouse gas emission savings of commercial and industrial waste-derived bioethanol production in Finland using the methodology introduced in the Directive on the promotion of the use of energy from renewable sources in the European Union (2009/28/EC). Four different interpretations of the Directive were considered as possible for the studied concept. All these options were calculated with three different process values.

The project was jointly carried out by VTT Technical Research Centre of Finland and Pöyry Forest Industry Consulting Oy within the EU funded project Bioenergy Network of Excellence (Bioenergy NoE).

The project group was formed by Research Director Kai Sipilä, Deputy Technology Manager Tuula Mäkinen, Senior Research Scientist Sampo Soimakallio, and Research Scientist Kati Koponen from VTT, and Analyst Esa Sipilä from Pöyry Forest Industry Consulting Oy. The authors would like to acknowledge their gratefulness to the financier and to the project group for their useful comments during the project.

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Contents

Abstract	3
Preface	5
List of symbols	7
1. Introduction	9
2. General description of the RED	11
3. Methodology.....	14
3.1 Description of the waste ethanol concept.....	14
3.2 Description of the RED methodology for biofuels and other bioliquids.....	17
3.2.1 Overview of the methodology.....	17
3.2.2 Calculation formula for the GHG emissions of biofuels and other bioliquids ...	17
3.2.3 Allocation method.....	19
3.2.4 Emissions of electricity and heat production	19
3.3 Interpretation of the RED methodology for the case study	20
3.3.1 Combined biofuel process and CHP plant	20
3.3.2 Separated biofuel process and CHP plant	21
3.4 Parameter assumptions for the calculation procedure	23
4. Results	25
4.1 Interpretation of the results	25
4.2 Sensitivity analysis.....	29
4.3 Special supplement considerations of the case study	31
4.3.1 Use of carbon capture and storage technologies.....	31
4.3.2 Use of substitution method.....	31
4.4 Comparison of the results.....	34
5. Discussion.....	36
6. Conclusions.....	39
References.....	41

Appendices

Appendix A: Input and output figures of different cases and system boundary options

Appendix B : The GHG emission saving default values presented in the RED

List of symbols

a	Year
°C	Celsius degree
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power plant
CIW	Commercial and Industrial Waste
CO ₂	Carbon Dioxide
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 savings from carbon capture and geological storage
e_{ccr}	Emission savings from carbon capture and replacement
e_{ee}	Emission savings from excess electricity from cogeneration
EC	European Commission
eq	Equivalent
EtOH	Ethanol
EU	European Union
g	Gramme
GHG	Greenhouse gas
MJ	Megajoule
MSW	Municipal Solid Waste
MWh	Megawatt-Hour
RED	Directive on the promotion of the use of energy from renewable sources in the European Union, 2009/28/EC
REF	Recovered Fuel
t	Tonne
TJ	Terajoule
tkm	Tonne-kilometre
VTT	VTT Technical Research Centre of Finland

1. Introduction

On 10 January 2007 Commission of the European Communities proposed that the European Union (EU) pursues in the context of international negotiations the objective of 30% reduction in greenhouse gas (GHG) emissions by developed countries by 2020 compared to 1990 level. This is necessary to ensure that emission reductions of 60–80% in 2050 compared to 1990 may take place aiming to limit the global mean temperature increase to 2 °C from the pre-industrial level (EC 2007).

On 23 January 2008 the European Commission announced an integrated proposal for Climate Action (EC 2008). The proposal includes two key targets: a reduction of at least 20% in GHG emissions by 2020 from the level of 1990 and a 20% share of renewable energy in the EU final energy consumption by 2020. The target for GHG emission reductions increase to 30% if there is an international agreement committing other developed countries to comparable emission reductions and economically more advanced developing countries to contributing adequately according to their responsibilities and respective capabilities (EC 2008).

Directive on the promotion of the use of energy from renewable sources in the EU (Directive 2009/28/EC, so called RED) was announced in the beginning of 2008 as a part of the integrated proposal for Climate Action and published in the Official Journal of the European Union 5 June 2009 (EC 2009). It establishes an overall binding target of a 20% share of renewable energy sources in energy consumption and a 10% binding minimum target for renewable energy sources in transport to be achieved by each Member State, as well as binding national targets by 2020 in line with the overall EU target of 20%. It states that the binding character of the biofuel target is appropriate subject to production being sustainable, second-generation biofuels becoming commercially available and Directive 98/70/EC of the European Parliament and of the Council of 13

1. Introduction

October 1998 relating to the quality of petrol and diesel fuels and amending Council Directive 93/12/EEC9 being amended to allow for adequate levels of blending (EC 2009).

The RED introduces environmental sustainability criteria for biofuels and other bioliquids that should be met to compliance with the targets presented in the RED and to benefit from national support systems. It states that GHG emission saving from the use of biofuels and other bioliquids taken into account for the purposes mentioned above shall be at least 35% for current biofuels, at least 50% after 1 January 2017, and at least 60% after 1 January 2018 for biofuels produced in installations in which production started on or after 1 January 2017. It also introduces a methodology to calculate GHG emissions of biofuels and other bioliquids as well as the GHG emission reduction compared to fossil fuels to be replaced. (EC 2009.)

The aim of this report was to test the methodology introduced in the RED to calculate GHG emission saving by using a case study based on commercial and industrial waste-derived bioethanol production in Finland. The key issue studied was whether the waste ethanol concept gains the 60% GHG emission saving according to the RED methodology or not. The impact of various possible interpretations of the methodology and the main uncertainties on the results were studied. In this study word *emission* refers to GHG emission.

2. General description of the RED

To help readers better understand the scope and the targets of the RED, some of the most important parts of the Directive concerning the GHG calculation methodology are presented here. The direct references to the RED (EC 2009) are separated with quotations marks and written with *Italic*.

The overall scope of the Directive is presented in the Article 1 as:

“This Directive establishes a common framework for the promotion of energy from renewable sources. It sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy and for the share of energy from renewable sources in transport. It lays down rules relating to statistical transfers between Member States, joint projects between Member States and with third countries, guarantees of origin, administrative procedures, information and training and, access to the electricity grid for energy from renewable sources. It establishes sustainability criteria for biofuels and bioliquids.”

The overall target of the European Union for the use of energy from renewable sources is stated in Article 3(1):

“...mandatory national overall targets are consistent with a target of at least a 20% share of energy from renewable sources in the Community's gross final consumption of energy in 2020...”

For each Member State, national targets for the share of energy from renewable sources in gross final consumption in 2020 are defined. These targets are presented in the Annex I of the RED. For Finland this target is 38%. For calculation of the share of energy from renewable sources, Article 5(1) states that:

“The gross final consumption of energy from renewable sources in each Member State shall be calculated as the sum of:

2. General description of the RED

- a) *gross final consumption of electricity from renewable energy sources*
- b) *gross final consumption of energy from renewable sources for heating and cooling*
- c) *final consumption of energy from renewable sources in transport.”*

The renewable energy sources in transport are for example biofuels. The term “biofuel” is defined in the Article 2 and means “*liquid or gaseous fuel for transport produced from biomass*”.

The target for the use of energy from renewable sources in transport is mentioned in Article 3(4):

“Each Member State shall ensure that the share of energy from renewable sources in all forms of transport in 2020 is at least 10% of final consumption of energy in transport in that Member State. For the purposes of this paragraph, the following provisions shall apply:

- a) *For the calculation of the denominator, that is the total amount of energy consumed in transport for the purposes of the first subparagraph, only petrol, diesel, biofuels consumed in road and rail transport, and electricity shall be taken into account.*
- b) *For the calculation of the numerator, that is the amount of energy from renewable sources consumed in transport for the purposes of the first subparagraph, all types of energy from renewable sources consumed in all forms of transport shall be taken into account.*
- c) *For the calculation of the contribution from electricity produced from renewable sources and consumed in all types of electric vehicles for the purpose of points (a) and (b), Member States may choose to use either the average share of electricity from renewable energy sources in the Community or the share of electricity from renewable energy sources in their own country as measured two years before the year in question. Furthermore, for the calculation of the electricity from renewable energy sources consumed by electric road vehicles, that consumption shall be considered to be 2.5 times the energy content of the input of electricity from renewable energy sources...”*

Concerning the national renewable energy target and the target for the use of energy from renewable sources in transport Article 21(2) states that:

“For the purposes of demonstrating compliance with national renewable energy obligations placed on operators and the target for the use of energy from renewable sources in all forms of transport referred to in Article 3(4), the contribution made by biofuels produced from wastes, residues, non-food cellulosic material, and ligno-cellulosic material shall be considered to be twice that made by other biofuels.”

Article 17 defines some sustainability criteria for biofuels. In the paragraph 2 the GHG emission saving limits for biofuels are defined as:

“The greenhouse gas emission saving from the use of biofuels and bioliquids taken into account for the purposes referred to in paragraph 1 of this Article shall be at least 35%. With effect from 1 January 2017, the greenhouse gas emission saving from the use of biofuels and bioliquids taken into account for the purposes referred to in paragraph 1 of this Article shall be at least 50%. From 1 January 2018 that greenhouse gas emission saving shall be at least 60% for biofuels and bioliquids produced in installations in which production started on or after 1 January 2017.”

The methodology for calculation of the emission saving is presented later in this report. There is also default values presented for the emission savings of different biofuels and they can be found from the Appendix B. However, these default values can only be used if the annualised emissions from carbon stock changes caused by land-use change are equal to or less than zero (Article 19(1a)).

3. Methodology

3.1 Description of the waste ethanol concept

The case discussed in this report is a waste-derived biofuel production technology under development. In the studied concept bioethanol production and a combined heat and power production plant (CHP) are integrated together. The raw material of the process is commercial and industrial waste (CIW). Bioethanol is produced from lignocelluloses separated from the waste material and the rest of the waste is used for energy production at the CHP plant.

The waste is sorted mechanically for the ethanol production and for the CHP plant, and recyclable materials (e.g. metals) are separated for recycling. The outputs of the process are waste ethanol, biogas, heat and electricity. Intermediate products of the ethanol process (e.g. slurry) are delivered to the CHP plant.

Carbon dioxide (CO₂) is produced in two points of the process; in the fermentation and in the waste combustion. In the biofuel process the fermentation of sugars to alcohols produces CO₂ as a co-product and the amount produced is approximately 1 tCO₂/tEtOH. Gas from fermentation is almost pure CO₂ and it can be cleaned to meet requirements for food production. The CO₂ from fermentation is based on renewable source and it doesn't have an effect to GHG balance. The other source of CO₂ is the waste combustion that takes place in fluidised bed CHP power plant. This flue gas contains CO₂ from both renewable and fossil origins. The role of the nominal CO₂ emission of the fuel mix is handled in details later in this report.

The waste ethanol process takes electricity and heat needed from the CHP plant, and part of the electricity and heat is left over for sale. As an option, electricity can also be purchased from the national grid. The integrated system with different options of energy sources makes the system boundary setting

challenging, in accordance with the RED. A simplified material and energy balance of the process is presented in Figure 1.

It is not yet defined if a sterilisation of the waste material is needed to decrease microbiological risks in the ethanol process. As the energy consumption of the process depends on the need of sterilisation, two different assumptions for the requirement of heat and consequently for the left over heat and electricity, are presented. Also the amount of urea used in the process is uncertain. According to the recent test results, the amount of urea needed could be much smaller than previously expected, maybe only twentieth of the initially assumed need. Thus, a case with smaller amount of urea used in the process was also studied. Altogether, three cases with different process values were studied and are as follows:

- Case 1:* Sterilisation of waste is needed resulting in relatively high process heat demand.
- Case 2:* No sterilisation of waste is needed resulting in relatively low process heat demand.
- Case 3:* Similar to the Case 2 but the amount of urea needed in the process is smaller.

3. Methodology

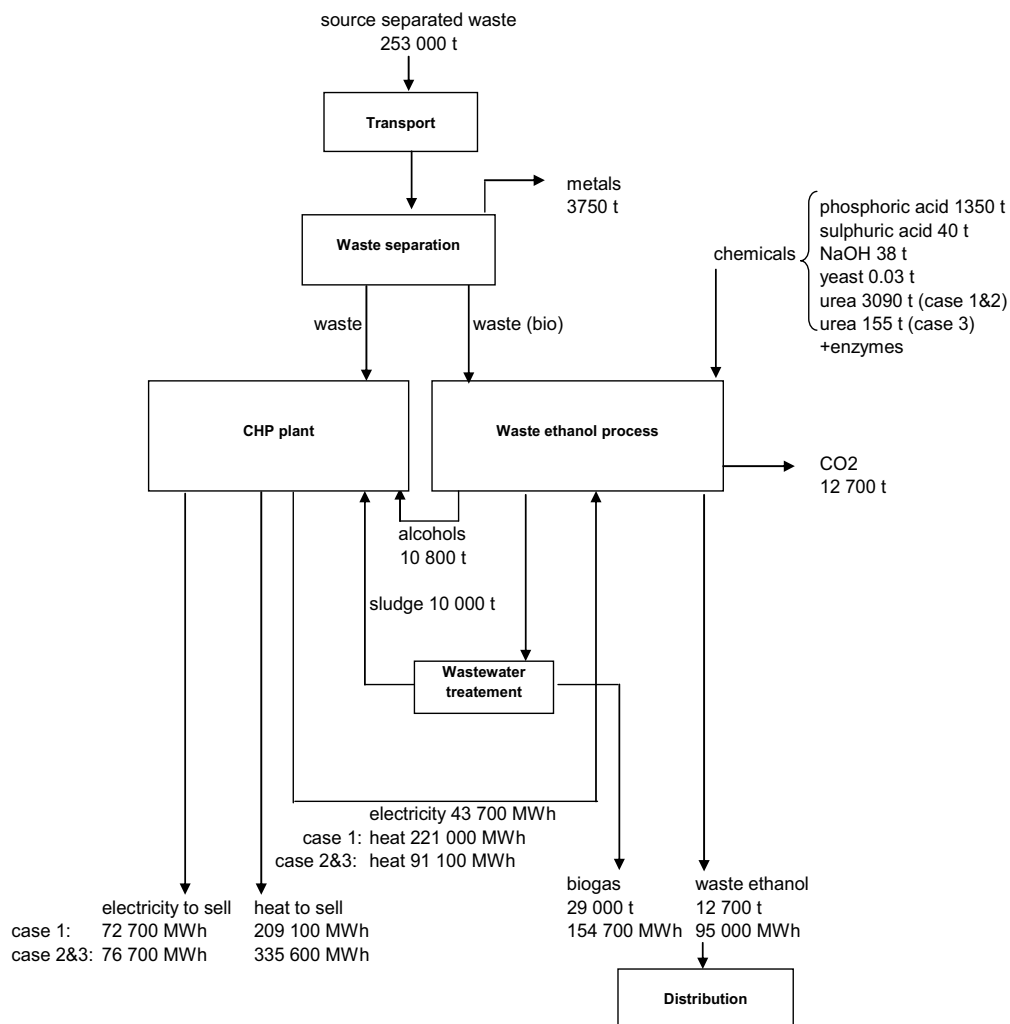


Figure 1. Material and energy balance of the waste-derived ethanol process.

3.2 Description of the RED methodology for biofuels and other bioliquids

3.2.1 Overview of the methodology

According to Article 17(2) of the RED, the emission saving from the use of biofuels and other bioliquids should be at least 35% (50% from 1 January 2017 and 60% from 1 January 2018 for biofuels and bioliquids produced in installations in which production started on or after 1 January 2017) for to compliance with the targets presented in the RED and to benefit from national support systems. Default values for a range of biofuels are provided in the RED. Actual values should be used when the default value for the emission saving from a production pathway is not presented. If the default value for emission saving lies below the required minimum level, the producer may calculate the emission saving with actual values to demonstrate that the actual emission saving from the production pathway is higher than the default value proposes. (EC 2009.)

Relative emission reduction in the GHG emissions achievable by replacing fossil fuel comparator by certain biofuel is defined in the RED (Annex V, part C) as:

$$EMISSION\ SAVING = (E_F - E_B)/E_F, \quad (1)$$

where

E_B = total emissions from the biofuel or other bioliquid and

E_F = total emissions from the fossil fuel comparator.

The RED provides default values for the emission savings of a few various future ethanol concepts including ethanol from straw, wood and farmed wood (EC 2009). However, it is not clear whether any of the proposed values are suitable to be used for the concept based on ethanol derived from municipal and industrial waste streams.

3.2.2 Calculation formula for the GHG emissions of biofuels and other bioliquids

The formula for calculation of the actual emission saving values is given in the part C of Annex V of the RED (EC 2009). It takes into account all the different

3. Methodology

phases of biofuel production. GHG emissions are expressed in terms of grams of CO₂ equivalent per MJ of fuel, gCO₂-eq/MJ, and are calculated as:

$$E = e_{ec} + e_l + e_p + e_{td} + e_u - e_{sca} - e_{ccs} - e_{ccr} - e_{ee}, \quad (2)$$

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 savings from carbon capture and geological storage

e_{ccr} = emission savings from carbon capture and replacement

e_{ee} = emission savings from excess electricity from cogeneration.

The RED offers explanations for all the terms of the formula 2. The consideration and relevance of the above mentioned terms for the case study discussed in this report are presented in the following.

Paragraph 18 of the part C of Annex V of RED states that when the raw material used in a biofuel process is waste, the emissions are only taken into account after collection of waste. Consequently, for the studied case the emissions from the extraction or cultivation of raw materials e_{ec} shall not be taken into account. Furthermore, emissions from carbon stock changes due to extraction or cultivation of raw materials e_l and emission savings by improved agricultural management e_{sca} shall be excluded from the calculation.

Paragraph 11 of the part C of Annex V of RED states that emissions from processing e_p include emissions from the processing itself and from the production of chemicals and other products used in the process. Also emissions from waste streams and leakage of the process shall be taken into account but are not present in the case discussed here. The emissions from the production of enzymes, sulphuric acid, phosphoric acid, caustic soda, yeast and urea required for the ethanol process shall be taken into account. In addition, emissions from production of electricity and heat needed in the ethanol process shall be considered.

Emissions from transport and distribution e_{td} include the emissions of the transport and storage of raw materials and distribution and storage of final products. The emissions from the fuel in use e_u are considered as zero for biofuels (paragraphs 12 and 13 of the part C, Annex V).

Carbon capture, and sequestration or replacement, are not considered in the emission calculations of the studied case, and therefore emission savings e_{ccs} or e_{ccr} shall be assumed to be zero. However, the impact of including such options on the results is discussed later.

Even though there is more electricity produced than needed in the waste ethanol process, the emission saving of the excess electricity e_{ee} shall not be taken into account. That is because the paragraph 16 of the part C of Annex V defines that the excess electricity produced by another co-product than an agricultural crop residue can not be considered as an emission saving.

3.2.3 Allocation method

The RED (paragraphs 17 and 18 of part C, Annex V) states that the allocation of emissions between the products inside the system boundary shall be carried out in proportion to the energy content of the products (determined by lower heating value in the case of co-products other than electricity). Co-products that have negative energy content shall be considered to have an energy content of zero for the purpose of the calculation. By taking into account the rules explained in the Chapter 3.2.2, allocation procedure is required for all the emissions that take place before the process step where the co-product is produced for the studied case. Consequently, all the emissions except those from waste ethanol distribution shall be divided to the main product and the co-products.

3.2.4 Emissions of electricity and heat production

The GHG calculation methodology of the RED defines that if the electricity used in the biofuel process is not produced within the fuel production plant, emissions shall be evaluated to be equal to the average emission intensity of the production and distribution of electricity in a defined region. However, if the power plant producing electricity for the biofuel process is not connected to the grid, emissions shall be assessed as an average production of the particular power plant. (EC 2009.)

3. Methodology

The RED does not directly state how emissions from CHP plant shall be allocated between power and heat when the plant produces power and/or heat to the biofuel process outside the defined system boundary. However, paragraph 18 of part C of Annex V indicates that energy-content-based allocation shall be used if electricity is not produced from agricultural crop residues.

3.3 Interpretation of the RED methodology for the case study

The RED does not determine unambiguously whether the biofuel process and the CHP plant are supposed to be handled as one combined process or as two separated ones. Therefore, it was possible to describe this biofuel and CHP plant system in a few various ways with different system boundaries. If these two processes were considered as one combined process, the energy used for biofuel production was self-produced. On the other hand, if they were handled as two separate processes, the electricity could be taken from the CHP plant or purchased from the national grid. Furthermore, the determination of the co-products depended on the system boundary.

The different options to interpret the RED methodology and to define the system boundary for the waste ethanol concept discussed in this report are illustrated in Appendix A (Figures A1–A4). All the options were calculated with three different process values (with and without the sterilisation of the waste and with variation in the amount of urea used in the process (see 3.1).

3.3.1 Combined biofuel process and CHP plant

Option 1 (Fig. A1)

The whole process was assumed to be one combined system, where the main input was municipal and industrial waste stream and the outputs were waste ethanol, biogas, electricity and heat. The emissions were allocated to all the outputs based on their energy content. The whole waste stream, except out-separated metals, was assumed to be combusted in the process.

Option 2 (Fig. A2)

The ethanol process and the CHP plant were considered as different parts of the same system. The electricity and heat were produced at the CHP plant and the ethanol process used energy from the own CHP plant. The inputs and outputs were the same as in the Option 1, but the waste was separated to the ethanol

production and to the CHP plant and only the waste at CHP plant was assumed to be combusted in the system.

System boundary setting for the Options 1 and 2 is presented in Figure 2.

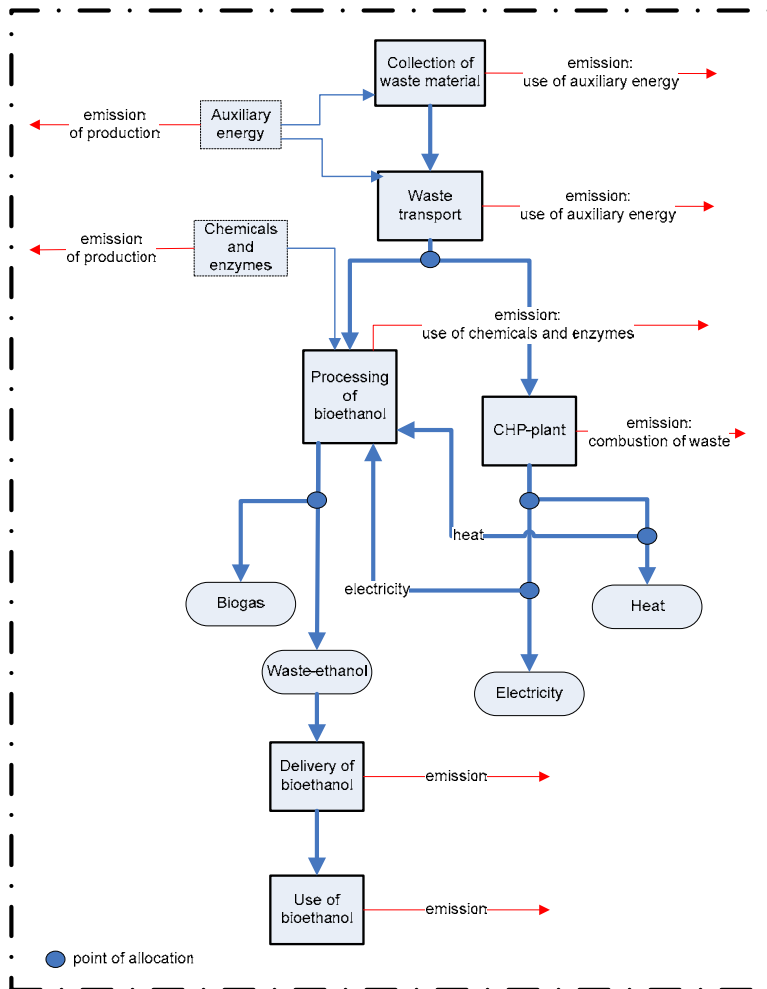


Figure 2. The system boundary setting for the studied Options 1 and 2 according to the RED.

3.3.2 Separated biofuel process and CHP plant

Option 3 (Fig. A3)

The ethanol process and the CHP plant were considered as two separate processes and the process emissions were calculated only for the ethanol process. The main inputs of ethanol process were waste, electricity and heat and

3. Methodology

the outputs were waste ethanol and biogas. The emissions of the ethanol process were allocated only to ethanol and biogas based on their energy content. Electricity and heat used in the ethanol process were taken from the CHP plant that used waste as fuel.

Option 4 (Fig. A4)

The Option 4 was similar to the Option 3 with the only exception that the electricity used in the process was purchased from the national grid and only the heat used in the process was assumed to be taken from the CHP plant.

System boundary setting for the Options 3 and 4 is presented in Figure 3.

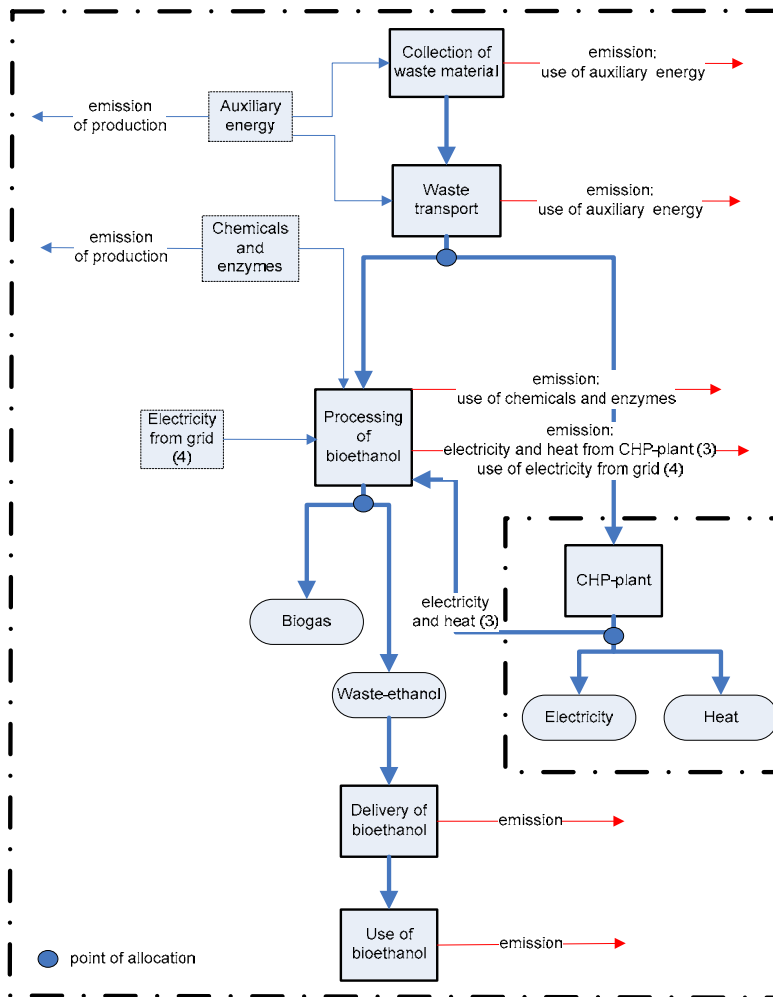


Figure 3. The system boundary setting for the studied Options 3 and 4 according to the RED.

3.4 Parameter assumptions for the calculation procedure

Several assumptions on the parameter values needed to be made for the calculation procedure. Firstly, the emission factor of the waste used as raw material and fuel was determined. Secondly, the average emission of the electricity purchased from the national grid was calculated for the Option 4. Thirdly, the emissions of transportation and distribution of the ethanol and the emissions of production of chemicals and enzymes required in the process were defined. In this study, literature and emission databases were used for evaluation of the GHG emissions of these parameters.

The emission factor of waste depends on the composition of the waste material used. The ratio of the fossil and biogenic components of waste affects to the amount of emissions produced. Also, the heat value of waste has an important role. In the national greenhouse gas inventory, the emission factor for mixed fuels, such as REF and municipal solid waste (MSW) is defined to be 31.8 gCO₂/MJ (Statistics Finland 2008). This default value is based on the assumption that the bio-content of waste is over 75 mass-%. In the case study discussed in this report, the bio-content of the waste was difficult to determine exactly, but it might have been much lower than 75 mass-%, maybe only 20 mass-%. Consequently, appropriate emission factor for the studied case should likely have been higher than 31.8 gCO₂/MJ. However, the value of the national inventory was used in the calculation but implications of varying the emission factor of waste were studied in the sensitivity analysis presented later in this report.

The average emission factor of electricity from the national grid was necessary for calculating the Option 4. The average emission was estimated according to the statistics of the GHG emissions of electricity production in Finland during years 2000–2006, and was calculated to be 65.6 gCO₂/MJ (Statistics Finland 2007).

The emissions of waste transportation were evaluated by LIPASTO database of VTT Technical Research Centre of Finland. The transportation distance was set to be 30 kilometres to one direction and transport was assumed to be done with a garbage truck carrying loads of 14 tons of waste. Consequently, during one year approximately 18 100 loads of waste were assumed to be transported to the ethanol process. The emissions of the transportation were 5 kgCO₂/tkm (LIPASTO 2006).

The chemicals used in the waste ethanol process were sulphuric acid, phosphoric acid, caustic soda, urea and yeast. The emissions were defined in

3. Methodology

accordance with the EcoInvent 2.0 database (Table 1) (Swiss Centre for Life Cycle Inventories). Also some enzymes were used in the ethanol process and the emissions of their production were estimated to be $1t_{\text{CO}_2\text{-eq}}/t_{\text{enzyme}}$ in accordance with Nielsen et al. 2007.

Table 1. The GHG emission factors of chemicals used in the waste ethanol process (Ecoinvent Data 2.0).

Chemical	Amount used t/a	Emission factor tCO ₂ -eq/tchemical
Phosphoric acid	1354	0.98
Yeast	0.03	0.49
Sulphuric acid	38	0.26
Caustic soda	38	0.50
Urea (Case 1&2)	3090	3.35
Urea (Case 3)	155	3.35

The emission factor used for distribution of ethanol was defined to be 1.74 gCO₂-eq/MJ in accordance with Edwards et al. (2007). The emissions of storage were assumed to be insignificant due to short storage times in the process and were therefore excluded.

All of the excess heat produced at the CHP plant was assumed to be used for district heating. However, this assumption might have overestimated the utilisation level, if there was more heat available than needed and not all of the excess heat produced was sold (that might be the case for example during the summer periods). However, the RED does not give specific guidelines for allocation procedure when the co-product has no further use. Emissions are allocated to the co-products according to their energy content, regardless of their end-use.

To calculate emission saving result, the use of ethanol was compared to the use of petrol as determined in the RED. The emission factor of the petrol was given in the RED equalling 83.8 gCO₂-eq/MJ (paragraph 19 of part C of Annex V).

4. Results

4.1 Interpretation of the results

The GHG emissions were allocated to waste ethanol in each option (Figures 4, 5 and 6 for Cases 1, 2 and 3, respectively). The results indicated the important role of heat used in the ethanol process as the major part of the emissions allocated to ethanol was from the heat production. This made the role of the emission factor determined for the waste combusted very significant. Also, the emission of electricity used in the process had an important role being dependent on the given emission factor as well. As verification of the emission factor for waste stream, containing varying concentration of fossil and biogenic components, was difficult, the associated uncertainty of the results could not be fully avoided.

The emissions of production of chemicals used in the ethanol process were significant especially for the Options 3 and 4, in which a larger part of the emissions was allocated to the ethanol. The major source of chemical emissions was production of urea. When the amount of urea used was only twentieth of the original amount, the emissions decreased notably (Figure 6). The contributions of waste transportation and ethanol distribution to the overall emissions were only minor.

4. Results

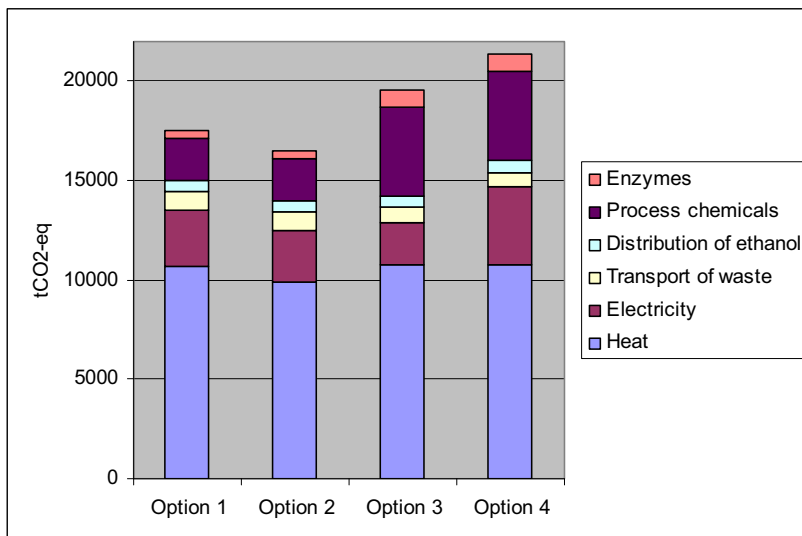


Figure 4. The GHG emissions from different sources allocated to waste ethanol, Case 1: with sterilisation.

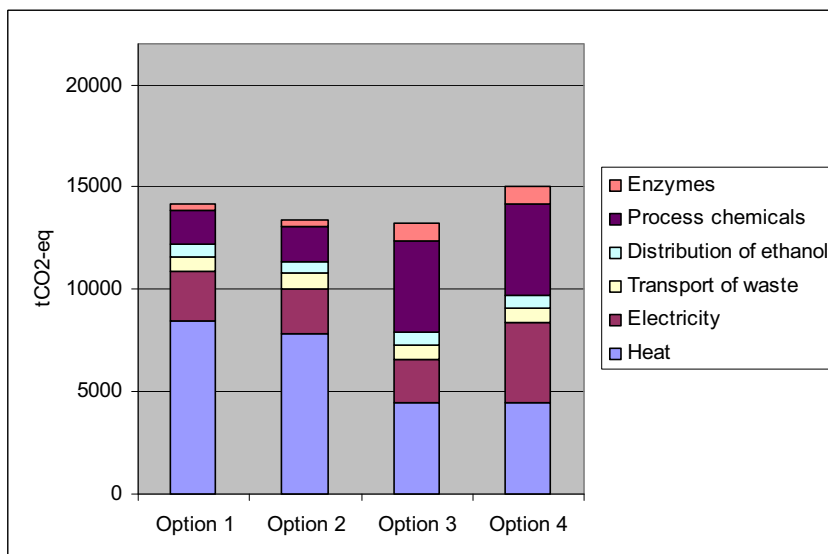


Figure 5. The GHG emissions from different sources allocated to waste ethanol, Case 2: without sterilisation.

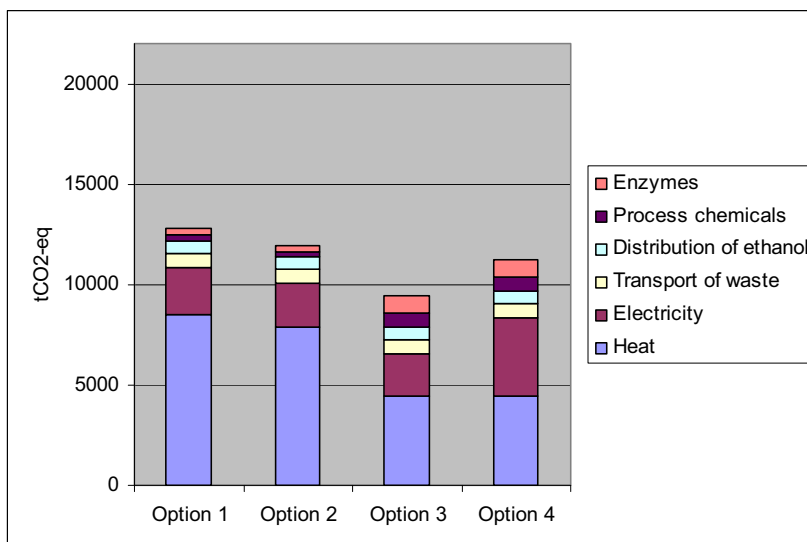


Figure 6. The GHG emissions from different sources allocated to waste ethanol, Case 3: with smaller amount of urea used, without sterilisation.

The emission saving result of the studied concept varied significantly because of the different system boundary settings and different allocations between the options (Table 2).

Table 2. GHG emission saving results for three different cases and four different RED interpretation options.

	CASE 1	CASE 2	CASE 3
Emission saving	%	%	%
Option 1	39	51	55
Option 2	42	53	58
Option 3	32	54	67
Option 4	26	48	61

In the Case 2, when no sterilisation of the waste was needed, the emission saving results were higher than in the Case 1, due to lower consumption of process heat. Consequently, in the Case 2 more heat could be sold out and more emissions were allocated to the co-products of the ethanol compared to the Case 1. When the required amount of urea was reduced, the emission saving results improved further (Case 3).

4. Results

In the Option 1 the ethanol process and CHP plant were considered as combined system and the whole waste stream was assumed to be combusted in the process. Therefore, more emissions were produced compared to the other studied options. However, the emissions were allocated to all the outputs (ethanol, heat, electricity and biogas), and thus the emissions allocated to the ethanol staid relatively low. The Option 1 could be seen as a reasonable way to handle the system because the emission factor used for the waste material was likely more correct than for the other options. When the whole waste stream was assumed to be combusted, the bio-content of the combusted waste was higher, because also the lignocellulosic part used for the waste ethanol production was included. As the bio-content of the combusted waste was higher, it could be assumed that the actual emission factor of the waste approached the emission factor of Statistics Finland used in the calculations (see 3.4). For all the other options the emission factor might have been too low, because the bio-content of the combusted waste was very likely lower than 75 mass-%.

In the Option 2 only the part of waste separated to the CHP plant was assumed to be combusted. The overall emissions were to some extent lower than in the Option 1. As the emissions were allocated to all the outputs (ethanol, heat, electricity and biogas) the emissions allocated to ethanol staid relatively low.

In the Options 3 and 4, the ethanol process and the CHP plant were considered as two separate processes. Only the emissions of energy needed for the ethanol process were taken into account. In these options the emissions from CHP plant were excluded, resulting in lower ethanol process emissions than in the Options 1 and 2. On the contrary, only biogas was considered as co-product, so the share of emissions allocated to the ethanol was higher. This had an important effect as the emissions of chemicals and enzymes were allocated only to the biogas and the ethanol (Figures 4 and 5). In the Case 3, where the amount of urea used in the process was significantly smaller, the emission saving results of the Options 3 and 4 were higher than in the corresponding case in the Options 1 and 2 (Figure 6).

In the Option 4 the electricity used in the process was assumed to be taken from the national grid. This resulted in higher emissions from consumed electricity, as the emission factor of electricity from the national grid was higher than the emission factor of electricity from the CHP plant.

4.2 Sensitivity analysis

As discussed earlier in this report, the emission factor of the waste combusted in the CHP plant was crucial for the overall emissions of the ethanol. In this study, sensitivity analysis was carried out by varying the emission factor of waste and observing its effect to the emission saving results of the studied options. The default value of the emission factor of waste was set to be 31.8 gCO₂/MJ and it was varied between 10 and 75 gCO₂/MJ. The selected range corresponded to the change of bio-content of the waste material approximately from 95 mass-% to 0 mass-%. When varying the emission factor, the emission saving results changed remarkably (Figures 7, 8 and 9). The emission saving decreased rapidly as the emission factor increased. Figures 7, 8 and 9 indicate also how the emission factor changed as a function of the wood and plastic (bio and fossil) contents of the combusted waste.

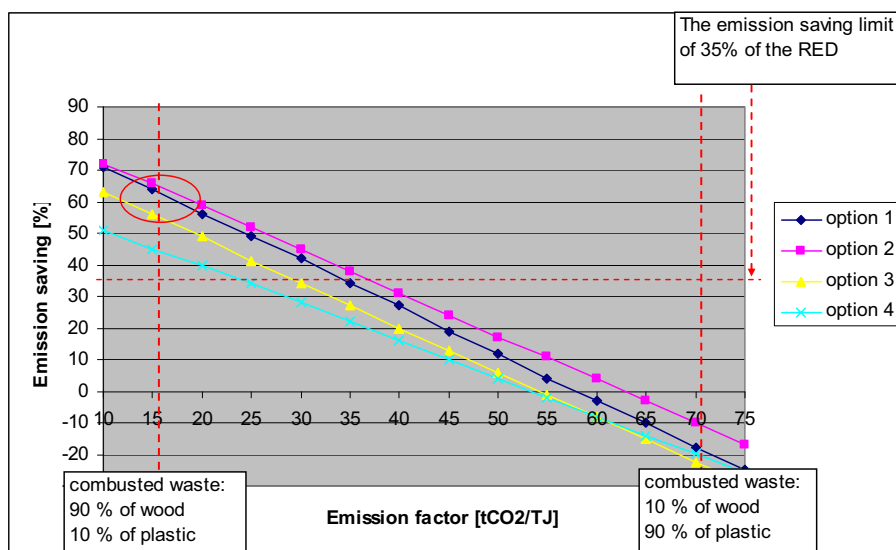


Figure 7. Impact of the emission factor on the emission saving result, Case 1: with sterilisation. The vertical lines on the left and right indicate the change of the emission factor due to change of the bio-content of waste. The horizontal line indicates the 35% emission saving limit of the RED. The areas marked with circles indicate the range where the 60% emission saving limit could be reached.

4. Results

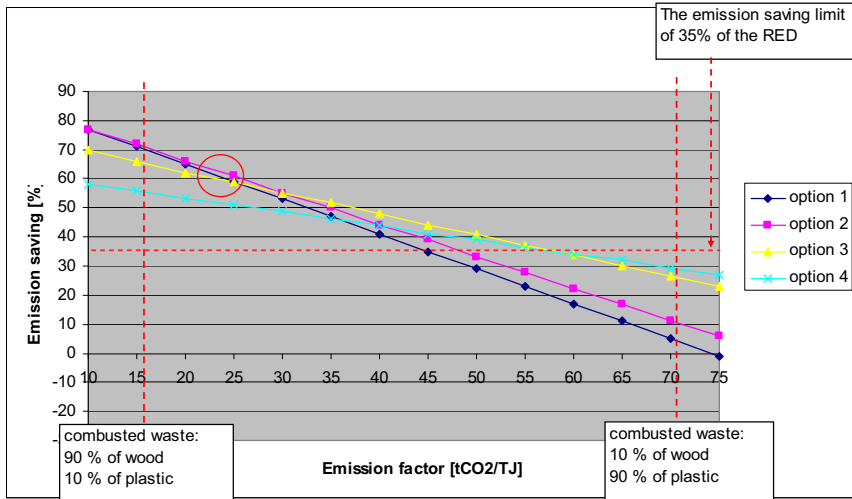


Figure 8. Impact of the emission factor on the emission saving result, Case 2: without sterilisation. The vertical lines on the left and right indicate the change of the emission factor due to change of the bio-content of waste. The horizontal line indicates the 35% emission saving limit of the RED. The areas marked with circles indicate the range where the 60% emission saving limit could be reached.

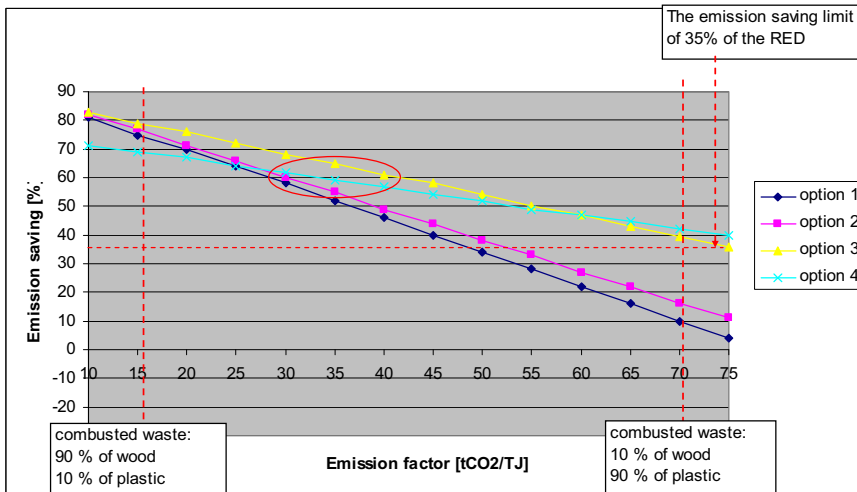


Figure 9. Impact of the emission factor on the emission saving result, Case 3: with smaller amount of urea used, without sterilisation. The vertical lines on the left and right indicate the change of the emission factor due to change of the bio-content of waste. The horizontal line indicates the 35% emission saving limit of the RED. The areas marked with circles indicate the range where the 60% emission saving limit could be reached.

4.3 Special supplement considerations of the case study

The RED allows the use of carbon capture and storage (CCS) technologies under certain conditions to gain higher emission saving results for biofuels. The influence of applying CCS on the results was studied. Also, the use of substitution method instead of energy allocation was applied to illustrate, how the emission saving results would have changed, if the substitution effects of the co-products of the ethanol had been considered.

4.3.1 Use of carbon capture and storage technologies

According to the RED the use of carbon capture and replacement technologies cause emission savings, which can be reduced from the emissions produced at the biofuel process, when CO₂ captured is used in commercial products or services and CO₂ from fossil origin is replaced (paragraph 15 of part C of Annex V). In the studied concept CO₂ was separated from the ethanol in fermentation in any case. Therefore, CO₂ capturing would have been technically easy to implement. Furthermore, this CO₂ flow was pure and therefore suitable for further use in many industrial purposes. If carbon capture and replacement had been applied for the CO₂ emissions of fermentation, the emission saving of waste ethanol would have varied from 42% to 71% depending on the system boundary setting and the technical assumptions.

If carbon capture and replacement or storage had been applied also to the fossil CO₂ emissions of the CHP plant (waste combustion), the emission saving result of the waste ethanol produced would have been as high as 80–95%. In this theoretic consideration only CO₂ from fossil origin was taken into account as emission credit (emission factor 31.8 gCO₂/MJ was used). In practise also the CO₂ from biogenic origin should have been counted and the amount of CO₂ captured and consequently the emission credit would have been even higher. However, as the uncertainty of the emission factor of the waste combusted here was remarkable, the theoretic consideration was carried out only for the CO₂ from fossil origin.

4.3.2 Use of substitution method

According to the RED the Commission shall use the values reported by Member States and shall evaluate whether and how the emission saving estimate would

4. Results

change if co-products were accounted for using the substitution approach (Article 23(4)). If energy allocation method was replaced by substitution method in the case of waste ethanol discussed in this report, the emission saving results would change notably. When substitution method is used, the allocation is avoided by extending the system boundary. The idea of substitution method is that the co-products of waste ethanol replace other products and emissions credits are gained when production of these replaced products is avoided. Here, the emission credits gained were counted for the ethanol.

The co-products of waste-derived ethanol were defined according to the system boundaries of different options as stated earlier. Two different values (minimum and maximum emissions credits) were evaluated for the products assumed to be substituted. Theoretic calculations with substitution method were made with assumptions presented in Table 3. The emission credits gained are presented in Table 4 and the emission saving results in Table 5.

Surplus and out-sold heat produced at the CHP plant was assumed to replace heat produced by biomass like wood in the minimum case and by peat in the maximum case. Similarly, surplus electricity was assumed to replace marginal electricity production whose minimum and maximum emission factors were set to be 300 and 900 gCO₂-eq/kWh, respectively, in accordance with Soimakallio et al. (2009). Co-produced biogas was assumed to replace natural gas in both cases. The metals separated from the waste stream in the beginning of the process were assumed to replace ore-based metals. Production of steel from recycled metals was defined to cause about 2tCO₂/t less emission than production from ore-based material (Tuhkanen et al. 2001).

Table 3. Assumptions for substitution method calculations.

Products of waste ethanol process	Products to be substituted		Emission factor of substituted product	
	min emissions	max emissions	min tCO ₂ /TJ	max tCO ₂ /TJ
Heat	Wood*	Peat**	0	132.4
Electricity	Min marginal emission	Max marginal emission	83.3	250
Biogas	Natural gas	Natural gas	55	55
Recycled metal	Ore-based metal		2 tCO ₂ /tmetal	

* Emissions considered as zero as the carbon is biogenic

** 80 % coefficient

Table 4. The amount of energy substituted and emission credits gained.

Products of waste ethanol process	CASE 1			CASE 2 AND CASE 3		
	Amount of energy substituted	Emission credit		Amount of energy substituted	Emission credit	
		min t	max t		min t	max t
	TJ			TJ		
Heat	753	0	99 661	1208	0	159 910
Electricity	262	21 807	65 448	276	23 010	69 058
Biogas	557	30 646	30 646	557	30 646	30 646
Recycled metal	3750 t _{metal}	7 500	7 500	3750 t _{metal}	7 500	7 500

Table 5. Emission saving results with substitution method.

	Emission before emission credits	Emission after emission credit		Emission factor of ethanol with substitution method		Emission saving with substitution method	
	t	min t	max t	min tCO ₂ /TJ _{ethanol}	max tCO ₂ /TJ _{ethanol}	min %	max %
CASE 1							
Option 1	95 264	35 311	-107 991	103	-316	-23	477
Option 2	89 568	29 615	-113 687	87	-332	-3	497
Option 3	50 417	12 271	12 271	36	36	57	57
Option 4	55 127	16 981	16 981	50	50	41	41
CASE 2							
Option 1	95 264	34 108	-171 850	100	-502	-19	699
Option 2	89 568	28 412	-177 546	83	-519	1	719
Option 3	33 723	-4 423	-4 423	-13	-13	115	115
Option 4	38 436	290	290	1	1	99	99
CASE 3							
Option 1	85 416	24 260	-181 698	71	-531	15	734
Option 2	79 720	18 564	-187 394	54	-548	35	754
Option 3	23 876	-14 270	-14 270	-42	-42	150	150
Option 4	28 588	-9 558	-9 558	-28	-28	133	133

The calculations carried out by using the substitution method provided results with remarkable variation (Table 5). This was due to the wide-ranging assumptions made for the calculation as the definition of the substitution benefits was difficult. Some of the results indicated that emission saving results with more than 100% emission saving could have been reached. It could be questioned, if the relative emission saving, calculated according to the methodology of the RED, was a reasonable indicator for measuring the emission savings of biofuel products. At least, the relative emission saving should not have been used as an indicator if substitution method had been used for the calculation. The more there were co-products, the more emission saving credits were counted for the primary product, like waste ethanol here. This led to a situation, where emission saving result was higher if smaller amount of primary product was produced, which did not seem logical. In other words, this meant that if more ethanol was produced the emission saving results got smaller. Consequently, the production of the co-products seemed to be more profitable than production of ethanol, when it came to GHG benefits.

4. Results

Although the extension of the system boundary, e.g. the use of substitution method, gives more comprehensive picture of the overall greenhouse gas impacts it is unclear if the substitution credits of power and heat should be allocated to the ethanol, in this particular case. Firstly, it is not evident that power and heat can be seen as co-products of ethanol as the raw material can be used directly for power and heat production without producing any ethanol. Secondly, every unit of ethanol produced reduced substitution credits of power and heat. These issues are crucial to be noted when interpreting the results of Table 5. However, if the raw material does not have any other use, the results calculated by using substitution method in Table 5 indicate that the use of raw material in the studied concept is likely favourable from the GHG benefit point of view. In this case, the interpretation of results calculated by RED methodology can lead to misleading conclusions of the overall GHG impacts.

4.4 Comparison of the results

Use of different technical variations and replacing energy allocation by substitution method gave a wide range of emission saving results for all three cases and all the four options. This variation showed the effect and importance of the method used and the assumptions made for the calculation. The emission saving results of different cases and different options are presented in Tables 6, 7 and 8.

Table 6. Emission saving results with different variations, Case 1: with sterilisation.

	Energy allocation			Substitution method	
	Basic case	CCS for CO2 of ethanol processing	CCS for CO2 of ethanol processing and CHP plant	min	max
CASE 1	%	%	%	%	%
Option 1	39	47	94	-23	477
Option 2	42	50	94	-3	497
Option 3	32	49	94	57	57
Option 4	26	42	80	41	41

Table 7. Emission saving results with different variations, Case 2: without sterilisation.

	Energy allocation			Substitution method	
	Basic case	CCS for CO2 of ethanol processing	CCS for CO2 of ethanol processing and CHP plant	min	max
CASE 2	%	%	%	%	%
Option 1	51	57	95	-19	699
Option 2	53	60	95	1	719
Option 3	54	71	94	115	115
Option 4	48	65	80	99	99

Table 8. Emission saving results with different variations, Case 3: smaller amount of urea used, without sterilisation.

	Energy allocation			Substitution method	
	Basic case	CCS for CO2 of ethanol processing	CCS for CO2 of ethanol processing and CHP plant	min	max
CASE 3	%	%	%	%	%
Option 1	55	62	100	15	734
Option 2	58	65	100	35	754
Option 3	67	84	107	150	150
Option 4	61	78	93	133	133

5. Discussion

The RED introduces a methodology for calculating the GHG emission savings for biofuels compared to fossil reference fuels. In this report the methodology was tested with a case study of bioethanol concept based on waste-derived bioethanol production integrated with CHP plant in Finland. The proposed methodology and the allocation method were introduced and the calculation was carried out according to the RED. The methodology was interpreted in several ways where room was left. In addition, the main uncertainties related to the assumptions of parameter set were studied. Some problematic features of the RED were recognised during the study, and are discussed in this Chapter.

Four different interpretations of the waste ethanol concept were considered as possible according to the RED. All these options were calculated with three different values (Case 1, Case 2 and Case 3) depending on the need of sterilisation of the waste material and the amount of urea used in the process, which are still under discussion. Within these four options differences in the system boundary setting and thus allocation of emissions took place resulting in differences in emission saving results. When drawing the system boundary the key question arising was, whether the CHP plant was part of the system or not.

The most important sources of the emissions were heat and electricity produced in the CHP plant. Such emissions were very prompt to variation in emission factor, which depended significantly on the plastic and moisture content of raw material to be combusted. Consequently, emission saving achieved depended remarkably on the given emission factor. The emission factor of waste was not well known and might vary between waste delivery lots. The uncertainty caused by emission factor could be significantly reduced only by exact measurement, which could be done e.g. by new bio-carbon methodology, based on measurement of ¹⁴C-isotope of the emitted combustion gas (Hämäläinen et al. 2007). The emission factor of waste combusted could be

reduced by increasing material recycling and by reducing the amount of plastic in combustion.

For biofuel producers the RED gives some additional options to reduce the amount of the GHG emissions of their biofuel processes. For example, carbon capture and geological storage is accepted as emission saving measure as well as carbon capture and replacement, if the CO₂ captured has further use in commercial products or services and if it replaces CO₂ produced from fossil origin. If one of these options was used for the waste ethanol process, the emission saving result could improve significantly. In the waste ethanol process CO₂ flow is separated from the ethanol flow anyway, which makes it relatively easy to apply carbon capture technology.

Similar effect as by CCS could be gained by replacing the fossil part (like plastics) of the waste combusted by biomass at the CHP plant. In this case, the emissions of the CHP plant would be notably smaller than when also the fossil waste is combusted. Consequently, also the emission saving results of the waste ethanol produced would be higher. Anyhow, if the fossil part of the waste material was separated and replaced by biomass, some other end-use should be found for the fossil waste. As the combustion of waste is becoming more and more general in Finland, the fossil part would probably be combusted in some other power plant. If this was the case, the final overall emission would be similar as the waste would have been combusted at the CHP plant of the waste ethanol process. The only difference would be that according to the calculation methodology of the RED, the waste ethanol produced would have a higher emission saving result.

The purpose of the RED is to give clear guidelines for actors on the biofuel sector for calculating the GHG emission savings of their products in order to ensure that the GHG benefits of biofuels accepted for the promoting target are at acceptable level. Anyhow, as presented in this case study, many different interpretations of the system boundary setting can be considered as possible, when applying the calculation methodology of the RED. The Directive does not provide exact information or clear definitions of the processes that should be included in or excluded from the system. The possibility for different interpretations and for different system boundary settings makes the evaluation and comparison of biofuel products more complicated and the uncertainty of emission saving results stays notable.

In the RED the GHG emissions are typically defined to be allocated between products based on their energy content. However, it should be noted that not all

5. Discussion

products are used for energy production purposes which can be the case e.g. for various materials, which makes the suitability of the particular allocation procedure more or less uncertain. For the waste ethanol concept discussed in this report, this may be the case if the excess heat produced can not be used as district heat in total (e.g. in summer times). However according to the RED, the emissions are allocated to heat based on the amount of production regardless of the exploitation level. This kind of allocation procedure is in conflict with the suggestions of published life cycle standards (ISO 14044) as it allocates emissions also to the waste streams not necessarily utilised.

In addition to allocation based on energy content of the products, the RED also defines the use of substitution method for assessing excess electricity produced from agricultural crop residue (see 3.2.4). However, there are no explanations why various methods are defined to be used for various products or raw materials. For example, it is unclear why excess electricity produced from forest residues or other non-agricultural renewable waste materials is treated differently than excess electricity produced from agricultural crop residues.

The relative emission reduction as an indicator as defined in the RED leads to a situation where the material input-output balance of biofuel process is ignored. Consequently, the emission saving results may look favourable for biofuel processes, where significant amounts of low GHG intensive raw materials are used in relation to the amount of biofuel produced. The emission saving indicator should take into account the resources used for the biofuel production. This kind of indicator could be for example the emission impact or saving in relation to bio-carbon, land area or money consumed, depending on the limited resource (e.g. Schlamadinger et al. 2005, JRC 2008, Soimakallio et al. 2009).

6. Conclusions

Some conclusion of application of the GHG calculation methodology of the RED to the waste ethanol concept can be drawn:

- There are several ways to interpret the RED methodology for calculation of the GHG emissions of the waste ethanol concept. It is not unambiguous if the waste ethanol process and the CHP plant are supposed to be handled as one combined process or two separated ones. When the default values of different parameters are used, the emission saving results of calculations according to the RED methodology vary from 26% to 42% in the Case 1 (with sterilisation), from 48% to 54% in the Case 2 (without sterilisation) and from 55% to 67% in the Case 3 (with smaller amount of urea used, without sterilisation).
- The GHG emission saving result of the waste ethanol is highly dependent on the emission factor given for the waste material combusted. The emission factor is the higher the higher are plastic and moisture content of waste. To gain results with over 60% emission savings, attention should be paid to minimization of the plastic content of waste material combusted in the CHP plant. Also the amount of urea used in the process should stay small. If the amount of urea staid high, the mass fraction of plastic of the waste material combusted should be less than 18 mass-%, so that emission savings of 60% would be gained (Case 2). If the amount of urea needed was smaller, the mass fraction of plastic should be less than 34 mass-% to gain 60% emission savings (Case 3).

6. Conclusions

- There is a possibility to improve the GHG emission saving result according to the RED by using carbon capture and replacement technologies.
- The RED methodology to calculate the GHG emission savings of biofuels is relatively narrow and does not reflect the consequences of increasing the production of biofuels. The key issues that are not considered in the RED methodology are at least the reference use of raw materials, land-area and auxiliary inputs, and the use of co-products. Thus, the RED methodology may provide higher GHG emission reduction result e.g. for certain crop-based biofuel compared to waste-derived biofuel although consequences in larger scale may be opposite. In order to avoid unintended promotion of less sustainable biofuels more extensive consideration of the GHG impacts is certainly required.

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Appendix A

Input and output figures for studied cases and system boundary options: The GHG emissions have been calculated for all the options and the results are presented in the following figures. In all the figures the waste ethanol and other outputs classified as co-products are marked on the colorized basis.

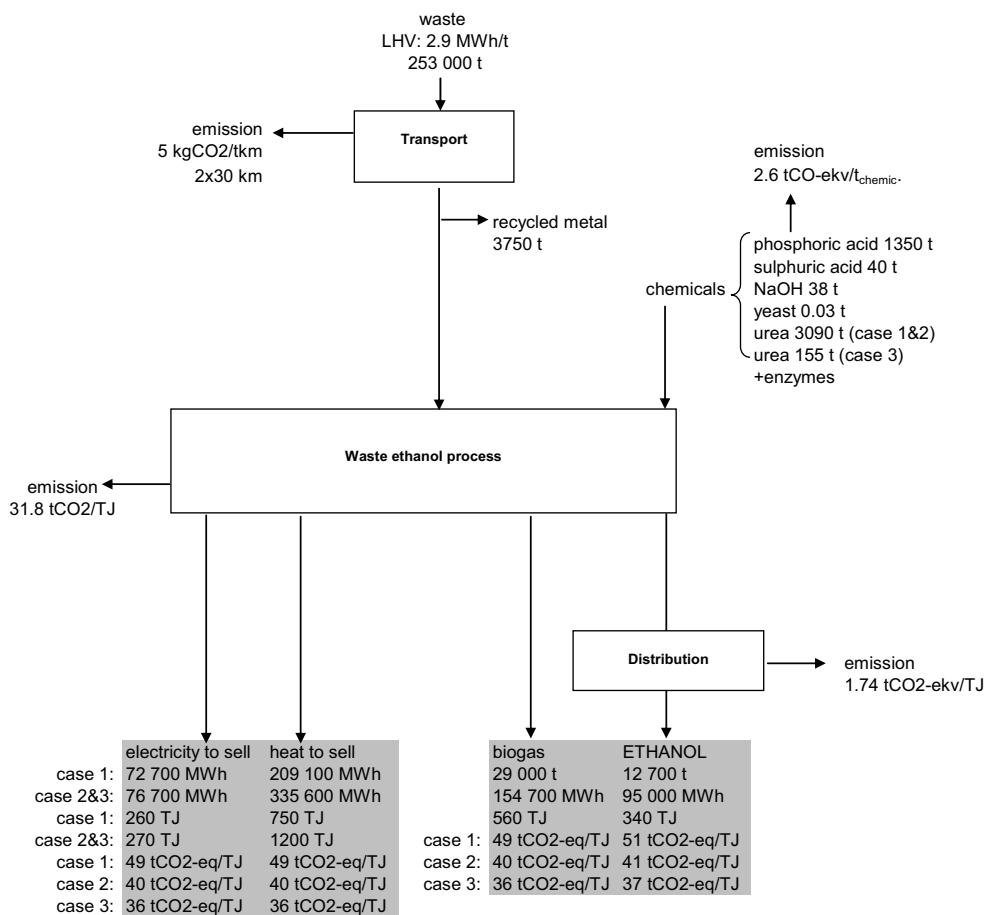


Figure A1. Inputs and outputs of the Option 1.

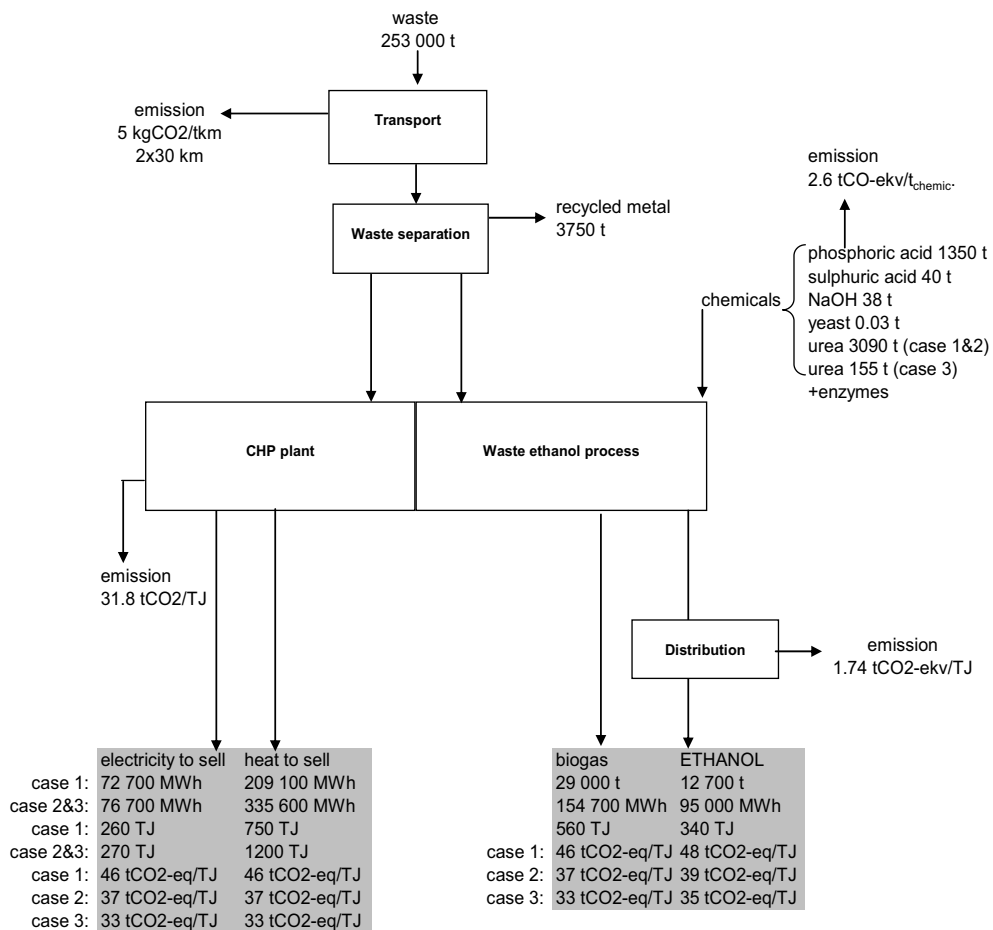


Figure A2. Inputs and outputs of the Option 2.

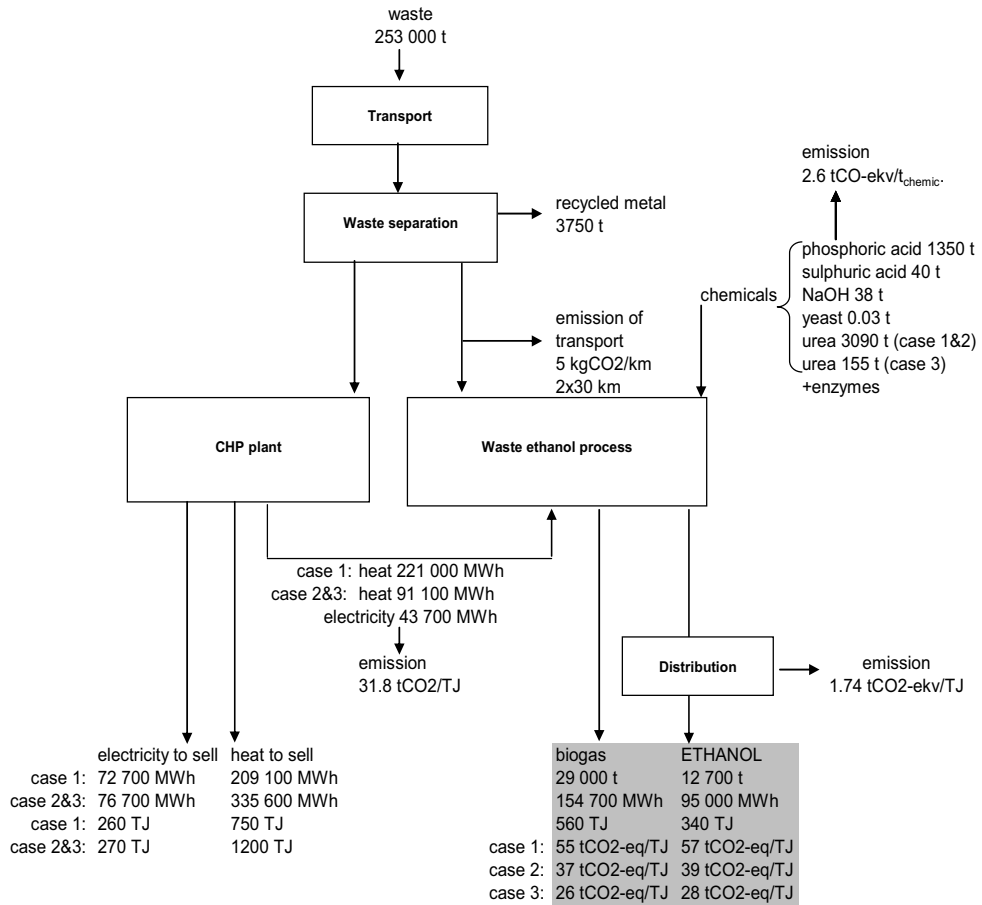


Figure A3. Inputs and outputs of the Option 3.

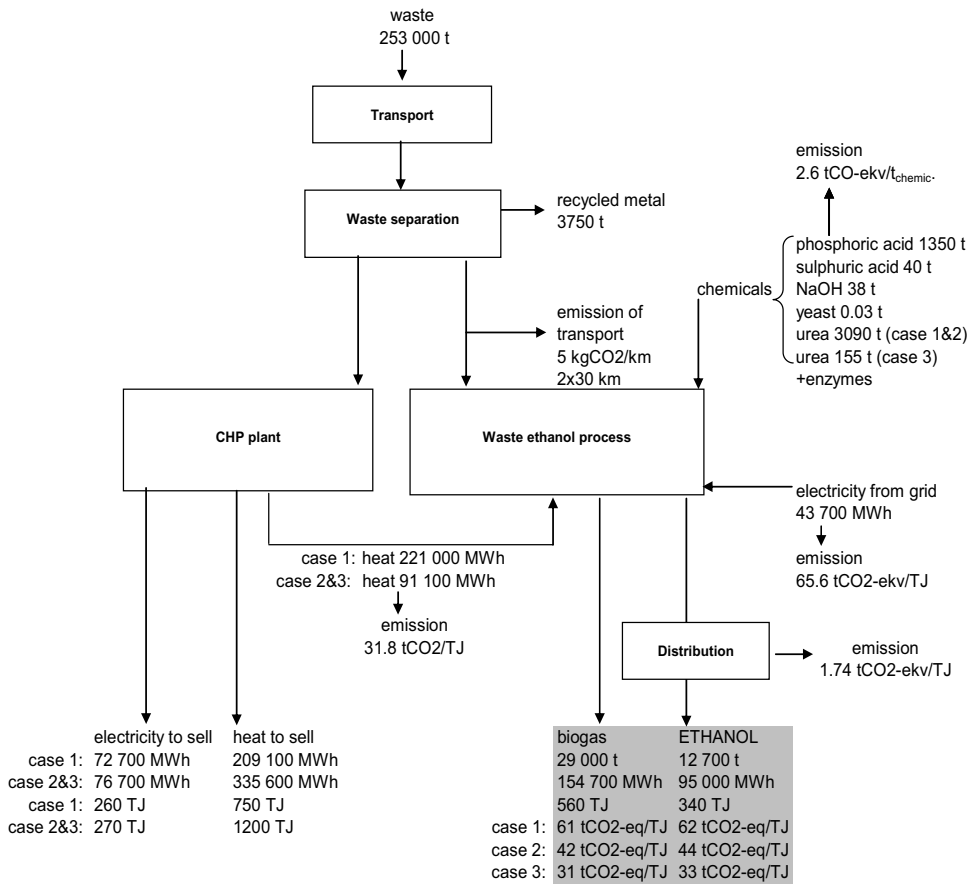


Figure A4. Inputs and outputs of the Option 4.

Appendix B

The GHG emission saving default values presented in the Annex V of the RED (EC 2009):

Typical and default values for biofuels if produced with no net carbon emissions from land-use change

Biofuel production pathway	Typical greenhouse gas emission saving	Default greenhouse gas emission saving
sugar beet ethanol	61 %	52 %
wheat ethanol (process fuel not specified)	32 %	16 %
wheat ethanol (lignite as process fuel in CHP plant)	32 %	16 %
wheat ethanol (natural gas as process fuel in conventional boiler)	45 %	34 %
wheat ethanol (natural gas as process fuel in CHP plant)	53 %	47 %
wheat ethanol (straw as process fuel in CHP plant)	69 %	69 %
corn (maize) ethanol, Community produced (natural gas as process fuel in CHP plant)	56 %	49 %
sugar cane ethanol	71 %	71 %
the part from renewable sources of ethyl-tertio-butyl-ether (ETBE)	Equal to that of the ethanol production pathway used	
the part from renewable sources of tertiary-amyl-ethyl-ether (TAEE)	Equal to that of the ethanol production pathway used	
rape seed biodiesel	45 %	38 %
sunflower biodiesel	58 %	51 %
soybean biodiesel	40 %	31 %
palm oil biodiesel (process not specified)	36 %	19 %
palm oil biodiesel (process with methane capture at oil mill)	62 %	56 %
waste vegetable or animal (*) oil biodiesel	88 %	83 %
hydrotreated vegetable oil from rape seed	51 %	47 %
hydrotreated vegetable oil from sunflower	65 %	62 %
hydrotreated vegetable oil from palm oil (process not specified)	40 %	26 %
hydrotreated vegetable oil from palm oil (process with methane capture at oil mill)	68 %	65 %
pure vegetable oil from rape seed	58 %	57 %
biogas from municipal organic waste as compressed natural gas	80 %	73 %
biogas from wet manure as compressed natural gas	84 %	81 %
biogas from dry manure as compressed natural gas	86 %	82 %

(*) Not including animal oil produced from animal by-products classified as category 3 material in accordance with Regulation (EC) No 1774/2002 of the European Parliament and of the Council of 3 October 2002 laying down health rules on animal by-products not intended for human consumption (1).

OJ L 273, 10.10.2002, p. 1.

Appendix B

- B. *Estimated typical and default values for future biofuels that were not on the market or were on the market only in negligible quantities in January 2008, if produced with no net carbon emissions from land-use change*

Biofuel production pathway	Typical greenhouse gas emission saving	Default greenhouse gas emission saving
wheat straw ethanol	87 %	85 %
waste wood ethanol	80 %	74 %
farmed wood ethanol	76 %	70 %
waste wood Fischer-Tropsch diesel	95 %	95 %
farmed wood Fischer-Tropsch diesel	93 %	93 %
waste wood dimethylether (DME)	95 %	95 %
farmed wood DME	92 %	92 %
waste wood methanol	94 %	94 %
farmed wood methanol	91 %	91 %
the part from renewable sources of methyl-tertio-butyl-ether (MTBE)	Equal to that of the methanol production pathway used	



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Title Assessing the greenhouse gas emissions of waste-derived ethanol in accordance with the EU RED methodology for biofuels		
Abstract Directive on the promotion of the use of energy from renewable sources in the European Union (EU), also called as RED, was published 5 June 2009 in the Official Journal of the EU (2009/28/EC). It establishes an overall binding target of a 20% share of renewable energy sources in the final energy consumption in the EU by 2020. In addition, a 10% binding minimum target for renewable energy sources in transport is set for each Member State. The RED also introduces environmental sustainability criteria for biofuels and other bioliquids. It states that the greenhouse gas (GHG) emission saving from the use of biofuels and other bioliquids taken into account for the national targets shall be at least 35% for current biofuels, at least 50% after 1 January 2017, and at least 60% after 1 January 2018 for biofuels produced in installations in which production started on or after 1 January 2017. The RED introduces a methodology to calculate the GHG emission savings of biofuels and other bioliquids compared to fossil fuels. In this report the methodology was tested with a case study based on commercial and industrial waste-derived bioethanol production integrated with a CHP plant in Finland. The aim of the report was to study whether the waste ethanol concept gains the 60% GHG emission savings according to the RED methodology or not. Four different interpretations of the RED methodology were considered possible for the studied concept. All these options were calculated with three different process values depending on the need of sterilisation of the waste material and the amount of urea used in the process. Within these four options differences in the system boundary setting and thus allocation of emissions took place resulting in differences in emission saving results. The key question was, whether the CHP plant and the biofuel process were supposed to be treated as one combined process or as two separated ones. The GHG emission savings over 60% were gained when the biofuel process and the CHP plant were assumed to be separate processes and the amount of heat and urea needed in the process were minor. The GHG emission saving of the waste ethanol was highly dependent on the emission factor given for the waste material combusted at the CHP plant. The emission factor was the higher the higher were the plastic and moisture contents of the waste. To gain results with over 60% emission savings, attention should be paid to minimization of the plastic content of waste material combusted. Over 60% emission savings could also be gained if carbon capture and replacement or storage were applied for the biogenic carbon dioxide released from the ethanol processing (fermentation).		
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European Union has established a 10% binding minimum target for the use of renewable energy sources in transport for each Member State by 2020 (Directive on the promotion of the use of energy from renewable sources in the European Union, 2009/28/EC). At the same time, the sustainability and the greenhouse gas balances of the liquid biofuels in transport are under constant discussion. European Union has responded to this debate by announcing its sustainability criteria and a calculation methodology for defining the greenhouse gas emission savings of transport biofuels. However, during this study it became evident that the EU methodology for calculating the emission savings of biofuels is open to various interpretations and does not give clear guidelines for the calculation procedure. Further discussion is needed concerning the criteria and the methodology presented in the directive when implementing the directive into national legislation and applying it into practice.