D5.1
Sustainability assessment

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D5.1 – Sustainability assessment	
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PUBLISHABLE SUMMARY

Sustainability means that the needs of the present generation are met without compromising the ability of future generations to meet their own needs. Issues concerning greenhouse gas emissions, biodiversity, carbon stock change and land use change are typically addressed in biomass sustainability schemes. In this report sustainability issues are assessed for five different Smart CHP supply chains by applying the European Renewable Energy Directive (REDII) emission reduction calculation methodology and other sustainability schemes, supplemented of a check of sustainability topics that are not or only partly included in sustainability schemes but play a role in the discussion on sustainability of bioenergy.

The sustainability of the following five Smart CHP supply chains from feedstock to end-user have been assessed:

- Corn stover (Romania, East EU)
- Softwood forestry residues (Sweden, North EU)
- Olive kernel wood (Greece, South EU)
- Miscanthus (Croatia, Central EU)
- Pyrolysis oil import scenario (Netherlands, West EU)

According to the REDII methodology, the total emissions from the use of pyrolysis oil for Combined Heat & Power application can be calculated by adding up the emissions from the extraction or cultivation of raw materials, emissions from the pyrolysis oil production process, and the emissions from pyrolysis oil transportation to end-users. The emissions expressed in gCO_2-eq/MJ are presented in Figure 1.

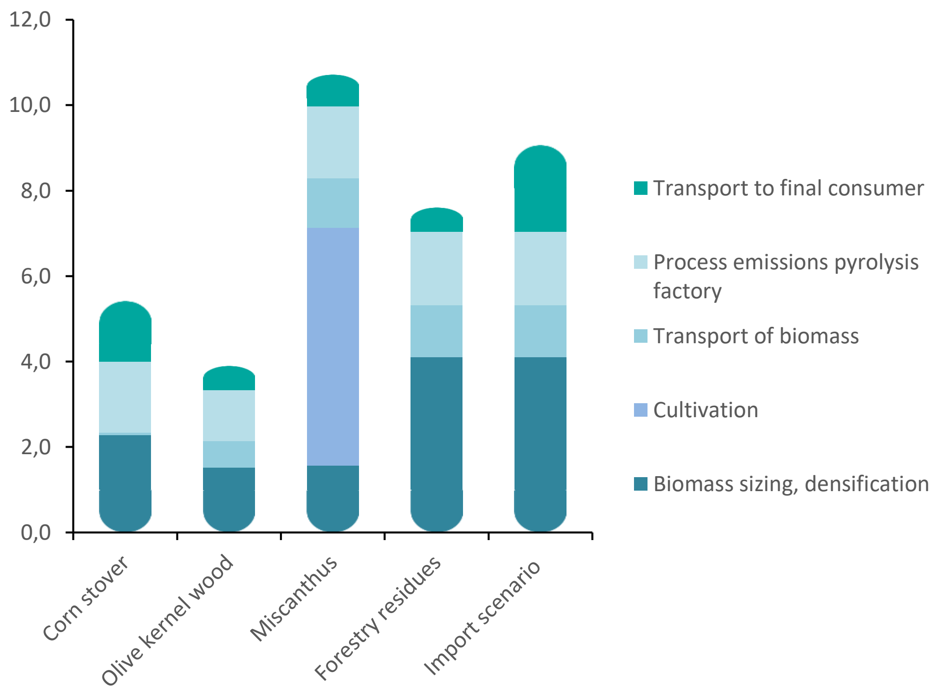

Figure 1: GHG emissions of the SmartCHP value chains (gCO_2-eq/MJ)

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The emission reductions compared to the fossil fuel comparators as found in the RED II are presented in Table 1.

Table 1: GHG emission reduction of the SmartCHP value chains at two transport distances

Biomass type	Corn stover	Olive kernel wood	Miscanthus	Forestry residues	Import scenario
Smart CHP electricity (50 km)	95%	96%	90%	93%	91%
Smart CHP heat (50 km)	96%	97%	92%	94%	93%
Smart CHP electricity (150 km)	94%	95%	89%	92%	90%
Smart CHP heat (150 km)	96%	96%	91%	93%	92%

Results show that the emission reduction values of all Smart CHP supply chains are in the order of 89% to 97%. This indicates that the calculated GHG emission savings exceeds the required target of 70% emission reduction for electricity, heating, and cooling production from biomass fuels used in installations starting operation after 1 January 2021 and 80% for installations staring operation after 1 January 2026 as laid out in article 29(10) of the RED II. Therefore, the energy produced from all Smart CHP supply chains can be accounted for national renewable energy targets and are eligible for financial support.

The following conclusions and recommendations can be made from the assessment of RED non GHG sustainability criteria and the sustainability risk assessment:

- Olive kernel wood has to comply to the RED II greenhouse gas emission reduction criteria only. Corn stover, forestry residues and miscanthus need to meet the RED II non-GHG sustainability criteria as well. It is expected that all selected feedstocks are able to meet these sustainability criteria regarding e.g. soil quality and soil carbon, biodiversity and carbon stocks. It has to be observed that at the time of writing, the RED II is still in the process of implementation. It is recommended to check the implementing acts which are not published yet at the time of writing and the still to be updated voluntary sustainability schemes at a later stage to confirm compliance with RED II.
- The National Inventory Reports (NIRs), in which the carbon balance at level of countries and EU as a whole are presented, show that the European forests have a stable carbon stock. Despite these facts, in some Member States the public opinion regarding the use of forest biomass is very negative. It is recommended to take the issue of carbon debt into account in the further work on public perception.
- All selected biomass types are included in RED II Annex IX of low Indirect Land Use (ILUC) risk biomass types, which indicates that the selected feedstocks are low ILUC risk feedstocks.
- The EU "*Guidance on cascading use of biomass with selected good practice examples on woody biomass* did not result in the identification of sustainability risks for the selected biomass types. The production of pyrolysis oil from biomass fits in the picture that various application, from energy to chemicals and products from low value residues are possible.

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List of Abbreviations

CHP	Combined Heat & Power
EC	European Commission
FPBO	Fast Pyrolysis Bio-Oil
GHG	Greenhouse Gas
LCA	Life Cycle Assessment
VPL	Virtual Plant Location

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CONTENT

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1. Introduction

Sustainability means that the needs of the present generation are met without compromising the ability of future generations to meet their own needs. The concept of sustainability is made tangible by definition of sustainability principles, criteria and measurable indicators. In case of biomass production and use the following themes are typically addressed: greenhouse gas savings, biodiversity, carbon stock change, land use change. These issues are typically addressed in biomass sustainability schemes. For pyrolysis oil used for energy or biofuel applications, the obligatory sustainability criteria as found in the Renewable Energy Directive (RED) apply, and from 2021 on the recast of the RED (RED II). Furthermore, in the context of the use of biomass, sustainability issues that are not well covered in a sustainability scheme can play an important role in public debate as well. Examples are indirect land use change, cascading use, and carbon debt.

1.1 Goal and scope

The sustainability of five Smart CHP supply chains from feedstock to end user will be assessed by

(i) calculation of the carbon emission reduction of value chains based on different feedstocks following the methodology of the Renewable Energy Directive (RED II), and a broader assessment of
(ii) sustainability topics covered in biomass sustainability schemes such as biodiversity, impacts on soil, water and air; and
(iii) other aspects, which are relevant but not covered in sustainability schemes (carbon debt, ILUC, cascading use/circular economy).

This deliverable presents a sustainability analysis of five Smart CHP supply chains from feedstock to end user. The report results in quantitative insight in RED II GHG reductions and identification of potential sustainability risks.

1.2 Approach

GHG emission reduction calculation

In this report the greenhouse gas emission reduction of the biomass types selected in the SmartCHP project (e.g. corn stover, olive kernel wood, miscanthus and forestry residues) is assessed using the methodology as found in the RED II. Generic data on biomass production, harvesting, collection and processing is based on JRC (2017). The pyrolysis process has been modelled in detailed by BTG. The emission reductions of the SmartCHP technology are compared to fossil fuel comparators. The resulting emission reduction needs to meet a certain minimum, e.g. 70% in case of electricity heating and cooling production from biomass fuels. Applications of biomass fuels that do not meet this emission reduction, do not account for national renewable energy targets, and are therefore, often not eligible for support. Therefore, the RED II emission reduction calculation is relevant from a legal point of view. In order to keep the calculation method simple and resulting

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in comparable results, a number of assumptions have been used. For instance, the emissions of construction of the pyrolysis plant or the conversion unit, are not taken into account for the sake of simplicity. Therefore, next to the judicially relevant GHG calculations of the RED II, a from scientific point of view more relevant LCA has been carried out. The LCA covering a wide range of environmental human health and fossil resources depletion related impacts can be found in Deliverable D5.2.

Other sustainability criteria covered by RED II and sustainability schemes

Other sustainability criteria, i.e. biodiversity and protection of carbon stocks are covered by assessment of the RED. Part of the RED compliant voluntary sustainability schemes, such as ISCC, RSB, and Better Biomass have even a broader coverage of sustainability issues than the RED, such as an indication of low ILUC risk biomass. For each sustainability criterion the relevance for the selected biomass types is indicated. Sustainability risks are not described at site level, but it is rather indicated whether reasonably sustainability risks can be expected, assuming that biomass production takes place following good practices. The risk assessment is valid for the EU28, in case country specific sustainability issues play a key role, the risk assessment is performed for the focus country.

Sustainability issues not covered by RED II and sustainability schemes

Sustainability issues not covered by sustainability schemes, such as indirect land use change, carbon debt, cascading use, compliance with waste hierarchy or circular economy principles will be described and applied to each of the selected feedstocks. Identified sustainability risks will not directly endanger sustainability certification, but could result in social acceptance issues, and are therefore very relevant. Social acceptance is described in more detail in Deliverable D5.3.

1.3 This report

In section 2.1 the GHG emission calculation method laid out in the recast Renewable Energy Directive (RED II) is described and tuned according to the selected Smart CHP supply chains. Subsequently, section 2.2 lists and describes all five smart CHP supply chains that have been selected for the sustainability assessment. These supply chains are then assessed on total emission values for biomass supply, the FPBO production process and transportation of FPBO from VPL to end-user in section 2.3, 2.4 and 2.5, respectively. In the following sections, the GHG emission reduction of all five Smart CHP supply chains are elaborated and compared to the targets set out in the recast Renewable Energy Directive. Finally, a conclusion is drawn about the findings in this report in section 2.8. Chapter 3 contains an assessment of the non-GHG RED II sustainability requirements, and chapter 4 an assessment of a selection of sustainability topics that are covered in sustainability schemes in a limited way, often relating to perception of bioenergy in general.

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2. GHG emission reduction calculation

2.1 RED II GHG emission calculation method

2.1.1 GHG emissions of bioliquids production

Part C of Annex V of the recast Renewable Energy Directive (EU) 2018/2001 (RED II) presents a greenhouse emission reduction calculation method according to the following equation:

$E = e_{ec} + e_{l} + e_{p} + e_{td} + e_{u} - e_{sca} - e_{ccs} - e_{ccr}$

Where:
E = total emissions from the use of the fuel (gCO_2-eq/MJ fuel)
e_{ec} = emissions from the extraction or cultivation of raw materials (gCO_2-eq/MJ fuel);
e_l = annualised emissions from carbon stock changes caused by land-use change (gCO_2-eq/MJ fuel);
e_p = emissions from processing (gCO_2-eq/MJ fuel);
e_{td} = emissions from transport and distribution (gCO_2-eq/MJ fuel);
e_u = emissions from the fuel in use (gCO_2-eq/MJ fuel);
e_{sca} = emission saving from soil carbon accumulation via improved agricultural management (gCO_2-eq/MJ fuel);
e_{ccs} = emission saving from CO_2 capture and geological storage (gCO_2-eq/MJ fuel);
e_{ccr} = emission saving from CO_2 capture and replacement (gCO_2-eq/MJ fuel).

Emissions from the manufacture of machinery and equipment shall not be taken into account.

A number of emission factors do not need to be taken into consideration and can be set at zero. The relevance of the emissions factors for the emission savings calculation of pyrolysis oil is discussed below.

Emissions from the extraction or cultivation of raw materials

Emissions from the extraction or cultivation of raw materials, e_{ec}, shall include emissions from the extraction or cultivation process itself; from the collection, drying and storage of raw materials; from waste and leakages; and from the production of chemicals or products used in extraction or cultivation. Capture of CO_2 in the cultivation of raw materials shall be excluded. (RED II, Annex V, part C, point 5).

The emissions from cultivation of raw materials is usually negligible, except in case of energy plantations. The emissions from the extraction of raw materials (harvesting and forwarding) need to be included in the greenhouse gas balance.

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Annualised emissions from carbon stock changes caused by land-use change

Annualised emissions from carbon stock changes caused by land-use change, e_l, shall be calculated by dividing total emissions equally over 20 years. For the calculation of those emissions the following rule shall be applied […] (RED II, Annex V, part C, point 7).

Land use change is not a topic if biomass is extracted from a forest that remains the status of a forest. Only if a forest is converted into e.g. agricultural land, this factor has to be taken into account. For all selected biomass types there is no land-use change and e_l = 0 g CO_2-eq / MJ.

Emissions from processing

Emissions from processing, e_p, shall include emissions from the processing itself: from waste and leakages; and from the production of chemicals or products used in processing (RED II Annex V, part C, point 11).

In the pyrolysis oil production process electricity, natural gas and chemicals are used. In addition, waste is created. In the greenhouse gas balance, the emissions from processing need to be included.

Emissions from transport and distribution

Emissions from transport and distribution, e_{td}, shall include emissions from the transport of raw and semi-finished materials and from the storage and distribution of finished materials. Emissions from transport and distribution to be taken into account under point 5 shall not be covered by this point (RED II, Annex V, part C, point 12).

Several emissions from transport and distribution can be identified. Examples are transport of raw material to the pyrolysis plant, shovel transport on the pyrolysis plant site and transport of pyrolysis oil to the end-user. All these emissions need to be taken into account in the greenhouse gas balance.

Emissions from the fuel in use

Emissions from the fuel in use, e_u, shall be taken to be zero for biofuels and bioliquids (RED II, Annex V, part C, point 13).

The pyrolysis oil can be categorised as a biofuel or bioliquids. Therefore e_u = 0 g CO_2-eq / MJ.

Emission saving from soil carbon accumulation via improved agricultural management

It is assumed that no emission savings will be claimed from soil carbon accumulation via improved agricultural management: e_{sca} = 0 g CO_2-eq / MJ.

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Emissions saving from carbon capture and geological storage

Emissions saving from carbon capture and geological storage, e_{ccs}, that have not already been accounted for in e_p, shall be limited to emissions avoided through the capture and storage of emitted CO_2 directly related to the extraction, transport, processing and distribution of fuel if stored in compliance with Directive 2009/31/EC on the geological storage of carbon dioxide (COM(767)2016, Annex V, part C, point 14).

In general, pyrolysis oil production is not combined with carbon capture and geological storage, therefore: e_{ccs} = 0 g CO_2-eq/MJ.

Emission saving from carbon capture and replacement

Emission saving from carbon capture and replacement, e_{ccr}, shall be related directly to the production of biofuel or bioliquid they are attributed to, and shall be limited to emissions avoided through the capture of CO_2 of which the carbon originates from biomass and which is used to replace fossil-derived CO_2 used in the energy or transport sector (COM(767)2016, Annex V, part C, point 15).

If during the pyrolysis production process to a bioliquid, or the further upgrading of the pyrolysis oil to biofuels CO_2 originating from the biomass feedstock is released and subsequently captured for use in the energy or transport sector, these emission savings could be taken into account. It is assumed that this is not the case, thus the emission savings from carbon capture and replacement are set to zero: e_{ccr} = 0 g CO_2-eq / MJ.

Conclusion

In the case of most pyrolysis plants the emission equation can be reduced to:

$$E = e_{cc} + e_p + e_{td}$$

Where:

E = greenhouse gas emissions from the use of pyrolysis oil;
e_{cc} = emissions from the extraction or cultivation of raw materials;
e_p = emissions from processing;
e_{td} = emissions from transport and distribution.

2.1.2 Emission reduction calculation

The RED II contains requirements to the minimum greenhouse gas emission saving from the use of biofuels (for transport) and bioliquids (for electricity, heating and cooling). Only biofuels and bioliquids that meet these requirements will be taken into account to national targets, renewable energy obligations and be eligible for financial support for the consumption of biofuels and bioliquids. The following minimum greenhouse gas emission savings need to be realised (RED II, article 29(10):

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The greenhouse gas emission saving from the use of biofuels, bioliquids and biomass fuels taken into account for the purposes referred to in paragraph 1 shall be:

(a) at least 50 % for biofuels and bioliquids produced in installations in operation on or before 5 October 2015;

(b) at least 60 % for biofuels and bioliquids produced in installations starting operation from 5 October 2015 until 31 December 2020;

(c) at least 65 % for biofuels and bioliquids produced in installations starting operation from 1 January 2021;

(d) at least 70 % for electricity, heating and cooling production from biomass fuels used in installations starting operation from 1 January 2021 until 31 December 2025; and 80% for installations starting operation from 1 January 2026.

An installation shall be considered to be in operation once the physical production of biofuels or bioliquids and of heating and cooling, and electricity for biomass fuels has started.

RED II, article 29(10)

The greenhouse emission savings from heat and cooling, and electricity being generated is calculated as follows (RED II Annex V, part C, point 3(b):

SAVING = $(EC_{F(h\&c,el)} - E_{B(h\&c,el)})/E_{F(h\&c,el)}$,

Where:
$E_{B(h\&c,el)}$ = total emissions from the heat or electricity
$E_{F(h\&c,el)}$ = total emissions from the fossil fuel comparator for useful heat or electricity.

In the RED II, the fossil fuel comparators of heat and electricity are fixed, i.e. 80 and 183 gCO_2-eq/MJ, respectively (RED II Annex V, part C, point 19).

For both the heat part and the electricity part of the CHP application an emission savings calculation is made. This means that, in case of CHP application, the emissions of the bioliquid before end-conversion need to be divided between the heat part and the electricity part. This is done by considering the electrical and heat efficiency, as well as the Carnot efficiency, i.e. the fraction of exergy in the useful heat. See next equations. This way the advantage of cogeneration having a high total efficiency resulting in high emission reduction savings compared to separate heating and electricity generation is calculated in a fair way.

For the electricity or mechanical energy coming from energy installations delivering useful heat together with electricity and/or mechanical energy (RED II, Annex V, part C, point 1(b)(iii)):

$$EC_{el} = \frac{E}{\eta_{el}}\left(\frac{C_{el}\cdot\eta_{el}}{C_{el}\cdot\eta_{el} + C_{h}\cdot\eta_{h}}\right)$$

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For the useful heat coming from energy installations delivering heat together with electricity and/or mechanical energy (RED II, Annex V, part C, point 1(b)(iii)):

$$EC_h = \frac{E}{\eta_h}\left(\frac{C_{el}\cdot\eta_h}{C_{el}\cdot\eta_{el} + C_{h\cdot\eta_h}}\right)$$

Where:

$EC_{h,el}$	=	Total greenhouse gas emissions from the final energy commodity.
E	=	Total greenhouse gas emissions of the bioliquid before end-conversion
η_{el}	=	The electrical efficiency, defined as the annual electricity produced divided by the annual fuel input based on its energy content
η_h	=	The heat efficiency, defined as the annual useful heat output divided by the annual fuel input based on its energy content
C_{el}	=	Fraction of exergy in the electricity, and/or mechanical energy, netto 100 % (C_{el} = 1)
C_h	=	Carnot efficiency (fraction of exergy in the useful heat).

The Carnot efficiency, Ch, for useful heat at different temperatures is defined as:

$$C_h = \frac{T_h - T_0}{T_h}$$

Where:

T_h	=	Temperature, measured in absolute temperature (Kelvin) of the useful heat at point of delivery
T_0	=	Temperature of surroundings, set at 273,15 Kelvin (equal to 0 °C)

If the excess heat is exported for heating of buildings, at a temperature below 150 °C (423,15 kelvin), Ch can alternatively be defined as follows:

C_h = Carnot efficiency in heat at 150 °C (423,15 kelvin), which is: 0,3546

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2.2 Smart CHP supply chains

Within the following sections, the emissions of five distinct SmartCHP supply chains from feedstock to end user are investigated. These supply chains have been carefully selected within WP2, encompassing:

- Corn stover (Romania, East EU)
- Softwood forestry residues (Sweden, North EU)
- Olive kernel wood (Greece, Southern EU)
- Miscanthus (Croatia, Central EU)
- Pyrolysis oil import scenario (Netherlands, West EU)

For all aforementioned feedstocks, the total emissions are calculating considering the following steps within the supply chain:

- Biomass supply, which includes:
  - Cultivation of raw materials
  - Processing, which involves extraction, collection, baling, chipping to wood chips, if applicable
  - Sizing from chips to particles appropriate to pyrolysis oil production
  - Biomass transport to the pyrolysis plant
- Pyrolysis oil production
- Transport of pyrolysis oil to SmartCHP unit.

The sizing of biomass to particles appropriate to pyrolysis oil production is an additional step not needed in standard wood chips applications, and is therefore calculated separately. For biomass transport to the virtual plant location (VPL) a range of 75 km is assumed resulting in 112,5 km of truck transport based on the assumption that the truck arrives at the plant gate having a full load and will, however, contain cargo during its return trip in 50% of the cases. For pyrolysis oil transport to end-user a minimum of 50 km and a maximum of 150 km range is assumed. In the case of the corn stover supply chain, a distance of 128 km is anticipated from VPL to end-user which is the exact distance from Kalizea corn processing (Slobozia) to the city of Bucharest. Here, it is assumed that the pyrolysis oil plant is situated near the Kalizea factory and that the SmartCHP unit is situated in the city of Bucharest.

2.3 Emissions from biomass supply

2.3.1 Romanian corn stover

Corn stover can be considered as agricultural residue with bulk density greater than 0,2 tonne/m^3 (JRC pathway no 11), and is described in JRC (2017). Taking into account the additional sizing of the corn stover bales into small particles together with biomass transportation, this results in total emissions of 2,0 g CO_2/MJ biomass.

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Cultivation

The estimate of the emission value from agriculture biomass cultivation is derived from the disaggregated default values for cultivation emissions provided in the Annex of the REDII. No emissions are allocated to the cultivation of the agricultural residues with bulk density greater than 0,2 tonne/m^3 (RED 2018/2001/EU, Annex VI, part C).

Processing (extraction/collection/chipping)

Agricultural residues, such as corn stover, require a pre-processing step before being transported. The collection of agricultural residues consists of baling and transportation (JRC pathway no 11). JRC (2017), p103 describes that the process of baling agricultural residues requires 0,01 MJ diesel/MJ bale, as well as emission of CH_4 and N_2O of 1,23E-05 and 3,03E-05 g/MJ bale respectively. Collection of corn stover has an emission of 0,88 gCO_2-eq/MJ biomass.

Sizing from bales to particles appropriate to FPBO production

Corn stover bales need to be properly sized prior to the process of converting biomass into FPBO. This can be achieved by using an haybuster. The energy requirement of chipping corn stover into properly sized material is 0,00225 kWh/MJ corn stover. Having an emission factor of 465 gCO_2-eq/kWh for electricity, this results in an emission of 1,05 gCO_2-eq/MJ.

Transport

It is assumed that the VPL is situated near the Kalizea corn processing factory in Slobozia, anticipating only 5 km of truck transport. The average energy requirement of truck transport is 0,94 MJ/t.km (Biograce 2014) and the LHV of corn stover is 12 MJ/tonne, which is used to translate tonnes to MJ. This results in an emission of 0,05 gCO_2-eq/MJ.

2.3.2 Swedish softwood forestry residues

Woodchips from forest logging residues (JRC pathway no 1) are described in detail in JRC (2017). Collectively, with additional sizing of the woodchips to smaller particles plus transport, this results in total emissions of 4,28 gCO_2-eq/MJ biomass.

Cultivation

No emissions are allocated to the cultivation of the forestry residues as reported within the disaggregated default values table provided in the Annex of the REDII.

Processing (extraction/collection/chipping)

As reported in JRC (2017), collection comprises forwarding, bundling/lifting, forestry machinery transport, loading and unloading. Here, it is stated that bundling of forestry residues is mostly applied in Scandinavian countries. By storage of

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bundled residues at the roadside over a period of 3 to 12 months, a moisture content reduction of the wood from 50% down to about 30% can be achieved. This is essential for both cost reduction and energy requirement concerning long-distance hauling of low-bulk, high moisture biomass like woodchips. However, seasoning also results in dry matter losses due to bacterial activity within the stored wood. In case of forest residues, the output of the collection is loose or bundled residues that require chipping. JRC (2017), p75 states that the process of wood chipping requires 0,00336 MJ diesel/MJ woodchips, as well as emissions of CH_4 and N_2O of 2,57E-06 and 1,07E-05 g/MJ woodchips respectively. The collection, seasoning and chipping to wood chips has an emission of 1,6 gCO_2-eq/MJ biomass.

Sizing from chips to particles appropriate to FPBO production

Measurements from BTG BTL (Gansekoele 2017) show that further sizing of wood chips using a hammer mill to particles appropriate to FPBO production requires about 30 kWh/tonne wet wood, resulting in an emission of 1,7 gCO_2-eq/MJ.

Transport

It is assumed that the biomass is transported over a distance of 75 km by truck (112,5 km of truck transport based on the assumption that the truck arrives at the plant gate having a full load and will, however, contain cargo during its return trip in 50% of the cases). The average energy requirement of truck transport is 0,94 MJ/t.km (Biograce 2014) and the LHV of woodchips is 9,5 MJ/tonne, which is used to translate tonnes to MJ. This results in an emission of 1,0 gCO_2-eq/MJ biomass.

2.3.3 Greek olive kernel wood

Olive kernel wood can be regarded as residues with bulk density greater than 0,2 tonnes/m^3 (JRC pathway no 12). This type of biomass is quite suitable for conversion into pyrolysis oil as it does not require intensive sizing prior to the FPBO production process. It must be noted that pre-processing values of all agricultural residues (JRC pathway no 12) are assimilated to the process for baling straw. The total emission of biomass supply is 1,8 gCO_2-eq/MJ biomass.

Cultivation

The estimate of the emission value from agriculture biomass cultivation is derived from the disaggregated default values for cultivation emissions provided in the Annex of the REDII. No emissions are allocated to the cultivation of the agricultural residues with bulk density greater than 0,2 tonne/m^3 (RED 2018/2001/EU, Annex VI, part C).

Processing (extraction/collection/chipping)

Following the approach of JRC (2017), processing of agricultural residues, which is based on the process for baling straw, requires 0,01 MJ diesel/MJ biomass. This results in total emissions of 0,88 gCO_2-eq/MJ.

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Sizing from chips to particles appropriate to FPBO production

Given the particle size, it is assumed that approximately 25% of the energy required for woodchips sizing should be applicable for further sizing of olive kernel wood prior to the pyrolysis oil production process. This indicates that proper sizing yields an emission of 0,4 gCO_2-eq/MJ.

Transport

It is assumed that the biomass is transported over a distance of 75 km by truck (112,5 km of truck transport based on the assumption that the truck arrives at the plant gate having a full load and will, however, contain cargo during its return trip in 50% of the cases). The average energy requirement of truck transport is 0,94 MJ/t.km (Biograce 2014) and the LHV of olive kernel wood is 17,22 MJ/tonne, which is used to translate tonnes to MJ. This results in an emission of 0,5 gCO_2-eq/MJ biomass.

2.3.4 Croatian miscanthus

Giant miscanthus (*Miscanthus x giganteus*) is a perennial, warm-season Asian grass. Giant miscanthus has been studied in the European Union and is now used commercially for heat and electricity generation. Although it is widely recognized as potential crop for cellulosic ethanol production, giant miscanthus has traits that likely make it better suitable for thermochemical conversion processes like pyrolysis. Mainly due to its low moisture and high lignin content, thermochemical conversion is preferred over biological conversion. The total emission of biomass supply is 6,8 gCO_2-eq/MJ biomass.

Cultivation

The emissions from cultivation of raw materials is usually negligible, however giant miscanthus is regarded as energy crop and therefore the associated emissions should be included in the greenhouse gas balance. Cultivation of giant miscanthus includes rhizome multiplication, crop establishment, crop maintenance and harvesting. Such cropping system is representative of typical current commercial miscanthus used for heat or power purposes. Miscanthus rhizomes are planted at densities of around 40.000 rhizomes/ha and are left for 2-6 years. Fertiliser input to the propagation sites depends on local soil fertility, as miscanthus is a low input crop[1]. The process of site establishment involves ploughing, power harrowing, planting, rolling and spraying[2]. Upon establishment, it has been recommended to apply organic fertiliser after years 2-3[3]. First year maintenance requires machinery movement to cut back the first year's growth. Miscanthus harvests typically occur in the second year of growth. Harvesting involves baling and subsequent movements to the roadside landing. The total emission of cultivations is calculated at 4,55 gCO_2-eq/MJ biomass.

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[1] I.F. Shield *et al.* The yield and quality response of the energy grass *Miscanthus x giganteus* to fertiliser applications of nitrogen, potassium and Sulphur, 2014

[2] DEFRA. Planting and growing *Miscanthus*. London United Kingdom, 2007

[3] DEFRA. Fertiliser recommendations for agricultural and horticultural crops. London United Kingdom, 2010

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Sizing from chips to particles appropriate to FPBO production

Miscanthus can be sized using a haybuster that require 27,1 kWh/tonne miscanthus, which corresponds to an electricity use of 0,00275 kWh/MJ biomass, resulting in 1,3 gCO_2-eq/MJ biomass.

Transport

It is assumed that the biomass is transported over a distance of 75 km by truck (112,5 km of truck transport based on the assumption that the truck arrives at the plant gate having a full load and will, however, contain cargo during its return trip in 50% of the cases). The average energy requirement of truck transport is 0,94 MJ/t.km (Biograce 2014) and the LHV of miscanthus is 9,8 MJ/tonne, which is used to translate tonnes to MJ. This results in an emission of 0,9 gCO_2-eq/MJ biomass.

2.3.5 Pyrolysis oil import scenario

The pyrolysis oil import scenario is based on pyrolysis oil production in Sweden by using forestry residues, which is subsequently imported from the harbor of Gothenburg to the harbor of Rotterdam. This scenario is quite similar to the Swedish softwood forestry residues case explained in section 2.3.2, however, the only difference is the additional marine transportation of FPBO from the port of Gothenburg to the port of Rotterdam. Therefore, the total emission of biomass supply is identical; 4,28 gCO_2-eq/MJ biomass.

2.3.6 Summary

The disaggregated emission values from biomass supply of all five Smart CHP scenarios are shown in Table 2. The highest emission value from biomass supply is observed for miscanthus. Clearly, this is due to the appointed cultivation emission values which is a consequence of being classified as energy crop.

Table 2: Summary of the GHG emissions of biomass supply of all five Smart CHP scenarios expressed in gCO_2-eq/MJ biomass

Emissions of biomass supply	Corn stover	Olive kernel wood	Miscanthus	Forestry residues	Import scenario (forestry residues)
Cultivation	0,0	0,0	4,6	0,0	0,0
Processing	0,9	0,9	0,0[a)]	1,6	1,6
Sizing	1,0	0,4	1,3	1,7	1,7
Transport	0,1	0,5	0,9	1,0	1,0
Total emissions	2,0	1,8	6,8	4,3	4,3

a) Emissions of processing are included in cultivation, as the cultivation subsystem includes baling and storage on the roadside.

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2.4 Emissions from FPBO production

Pyrolysis has become of major interest due to the flexibility in operation, versatility of the technology, and adaptability to a wide variety of feedstocks. Pyrolysis operates in anaerobic conditions where the constituents of biomass are thermally cracked to gases and vapours. In the process known as fast pyrolysis, biomass decomposed quickly to generate mostly vapours and some charcoal and gas. Fast pyrolysis operates at temperatures of 400-600°C and very short residence times of less than 2 seconds. After cooling and condensation of the vapours, a mobile liquid is formed called pyrolysis oil. The by-products char and non-condensable gases can be used within the process to provide the process heat requirements by combustion. The overall process is depicted and simplified in Figure 2. In addition, the energy balance of the pyrolysis process using corn stover is schematically shown, which is based on one full capacity production hour with a feedstock feeding rate of 5 tonnes per hour of dry biomass. The values outside the dotted line represents net energy inputs (i.e. corn stover, gas, and electricity) and net energy outputs (i.e. pyrolysis oil, steam, and electricity), which are fundamental for the RED emission reduction calculation.

Natural gas is solely needed for the start-up and shutdown of the process, after which the process is energy self-sufficient, i.e. more electricity and steam is generated tan used internally. Furthermore, the pyrolysis process requires about 95 kg of liquid nitrogen per hour, and small amounts of other chemicals, which will not be specified in detail for reasons of confidentiality. Nevertheless, these values are considered in the emission calculation. Also, the processing of waste streams such as ash, sewage water, used lubricating oil, municipal solid waste etc. is taken into account.

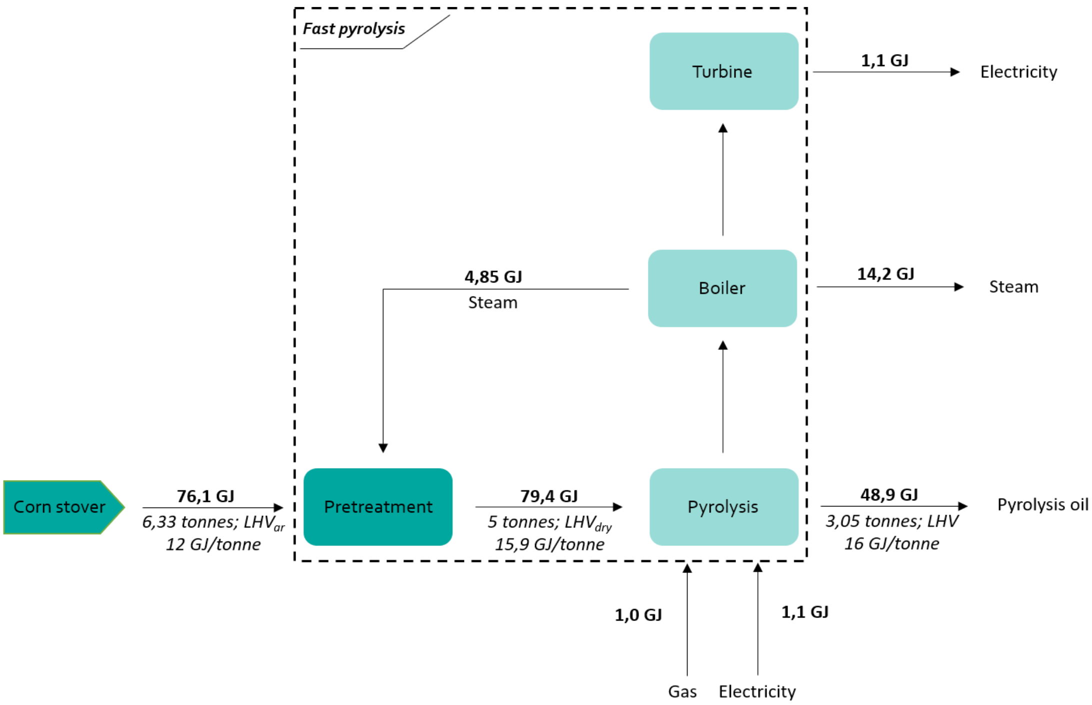

Figure 2: Energy balance of the pyrolysis process based on corn stover as feedstock

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Table 3 displays various assumed and calculated key properties of the selected feedstocks and their effect on the energy balance of the pyrolysis process. It must be noted that the import scenario encompasses oil importation that is produced from forestry residues. Therefore, four feedstock types are shown. The moisture content of the selected biomass is vital as it determines the required energy to a great extent. As a rule of thumb, the higher the moisture content the more energy must be spent for drying and the less energy (i.e. steam and electricity) can be delivered to third parties. Generally, wet woody biomass types require a larger dryer with higher electricity and heat consumption. For this reason, excess steam and electricity for third parties is less for woody biomass than, for instance, agricultural residues. Noticeably, the total energy efficiency of the pyrolysis oil production process is highest for olive kernel wood. The reason is that the energy content of dried olive kernel wood is substantially higher compared to the other feedstocks.

Table 3: Key feedstock properties at pyrolysis oil plant gate and their effect on the energy balance of the pyrolysis process

Biomass type	Corn stover	Olive kernel wood	Miscanthus	Forestry residues
Moisture content (%)	25%	13%	40%	41%
Ash content (%)	5,06%	0,7%	3,2%	3%
LHV_{ar} (GJ/tonne)	12,0	17,2	9,8	9,5
Biomass input (tph)	6,3	5,5	7,9	8,1
Biomass input (GJ/h)	76,1	94,3	77,5	76,5
Pyrolysis oil prod. (GJ/h)	48,9	44,2	48,2	50,2
Steam for third parties (GJ/h)	14,2	35,6	14,0	11,1
Electricity for third parties (GJ/h)	1,1	1,1	1,0	0,3
Total energy output (GJ/h)	64,1	80,9	63,3	61,6
Total energy efficiency PO production process	84%	86%	82%	81%

The greenhouse gas emissions of pyrolysis oil production are calculated based on the energy requirements from the individual feedstocks (Table 3), which are summarized in Table 4. The net electricity consumption is zero since the pyrolysis plant produces excess electricity, and thus production exceeds internal consumption. Minor variations in natural gas and liquid nitrogen consumption are observed as they are assumed to be dependent on the pyrolysis oil yield. Diesel is consumed during shovel movements for biomass handling, and dependent on the energy content of the biomass, higher or lower emission values can be found correspondingly.

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Table 4: Greenhouse gas emissions of the pyrolysis oil production process expressed in gCO_2-eq/tonne biomass

Biomass type	Corn stover	Olive kernel wood	Miscanthus	Forestry residues	Import scenario
Electricity	0,00	0,00	0,00	0,00	0,00
Natural gas	0,86	0,65	0,86	0,88	0,88
Diesel	0,04	0,03	0,04	0,04	0,04
Liquid nitrogen	0,35	0,26	0,35	0,36	0,36
Other process emissions	0,14	0,08	0,12	0,11	0,11
Total	1,39	1,02	1,38	1,39	1,39

2.5 Emissions from FPBO transportation

The transport emissions per MJ pyrolysis oil is calculated by means of the distance and the lower heating value of the pyrolysis oil. A conversion factor of 0,94 MJ/t.km and an emission factor of 87,6 gCO_2-eq/MJ (diesel) are applied from BioGrace, an EU accepted set of emission factors. The location of a Smart CHP unit is not clear for all scenarios. Here, a distance range is anticipated of 50 km (min.) and 150 km (max), which is 100 km (min.) and 300 km (max.) including the empty return trip. It is assumed that the truck is a dedicated one so that no other goods will be transported during the return trip. In the corn stover scenario, it has been clarified in section 2.2 that the VPL is situated near the Kalizea corn processing factory where the produced pyrolysis oil is transported to the city of Bucharest. The exact distance from the VPL to the city of Bucharest is 128 km. In the miscanthus scenario, the VPL is situated in Sisak where a large oil refinery complex is present. The produced pyrolysis oil is then transported to the city of Zagreb. The exact distance from the VPL to the city of Zagreb is 65 km. Lastly, in the import scenario, FPBO is transported by ship from the port of Gothenburg to the port of Rotterdam. The reported distance is 606 nautical miles[4] (nm) which corresponds to 1.222 km. Subsequently, it is transported by truck according to the same assumptions outlined above. A conversion factor of 0,12 MJ/t.km (ship/product tanker 50kt) and an emission factor of 87,2 gCO_2-eq/MJ (HFO) are applied from BioGrace. The calculated emissions are shown in Table 5.

Table 5: Greenhouse gas emissions of FPBO transportation expressed in gCO_2-eq/MJ pyrolysis oil

Biomass type	Corn stover	Olive kernels	Miscanthus	Forestry residues	Import scenario
Transport by truck 50 km (two ways)	1,42	0,57	0,75	0,55	0,55
Transport by truck 150 km (two ways)	1,66	1,71	1,72	1,66	1,66
Transport by ship	0,00	0,00	0,00	0,00	1,47

[4] Ports.com

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2.6 Total emissions of Smart CHP scenarios

Not only pyrolysis oil is produced within the process, but also steam and electricity as co-products. According to REDII, Annex V, part C point 17; *Where a fuel production process produces, in combination, the fuel for which emissions are being calculated and one or more other products (co-products), greenhouse gas emissions shall be divided between the fuel or its intermediate product and the co-products in proportion to their energy content.* Table 6 shows the allocation factor applied (i.e. the share of pyrolysis oil in the total energy output of the process) for all individual biomass types. The allocation factor is dependent upon the moisture content of the incoming biomass. Here, a higher moisture content of the incoming biomass results in a higher allocation factor and subsequent GHG emissions. Table 6 denotes the relatively high steam production from the use of olive kernel wood in the pyrolysis oil production process. The reason for the high steam production output is the combination of a low moisture and ash content of olive kernel wood with a relatively low pyrolysis oil yield (44 GJ/h). The energy content of olive kernel wood not transformed into pyrolysis oil is converted into steam which can be distributed to third parties.

Table 6: Energy allocation of biomass supply and pyrolysis oil production

Biomass type	Corn stover	Olive kernel wood	Miscanthus	Forestry residues
Pyrolysis oil prod. (GJ/h)	48,9	44,2	48,2	50,2
Steam for third parties (GJ)	14,2	35,6	14,0	11,1
Electricity for third parties (GJ)	1,1	1,1	1,0	0,3
Total energy output (GJ)	64,1	80,9	63,3	61,6
Share of pyrolysis oil in total energy output (%)	76%	55%	76%	81%

Figure 3 shows the emissions of all supply chain subsystems combined, expressed in gCO_2-eq/MJ pyrolysis oil. Major differences can be observed for biomass cultivation, biomass sizing and transportation. Obviously, the total emission value of the import scenario is greater compared to the scenario where forestry residues from Sweden are converted to pyrolysis oil. The import scenario is distinct from the forestry residues scenario by the additional marine transportation step in the value chain. Even though marine transportation is part of the import scenario, it does not show the highest overall emissions. Miscanthus is appointed the scenario that shows the highest overall emissions, owing to the required cultivation subsystem not involved in the other scenarios. Lastly, it becomes clear that agricultural residues like corn stover and olive kernel wood shows the overall lowest emission values compared to woody biomass (forestry residues) and energy crops (miscanthus). This can mainly be attributed to lower energy requirements for biomass sizing and densification, and with respect to energy crops, there is no cultivation subsystem required for agricultural residues.

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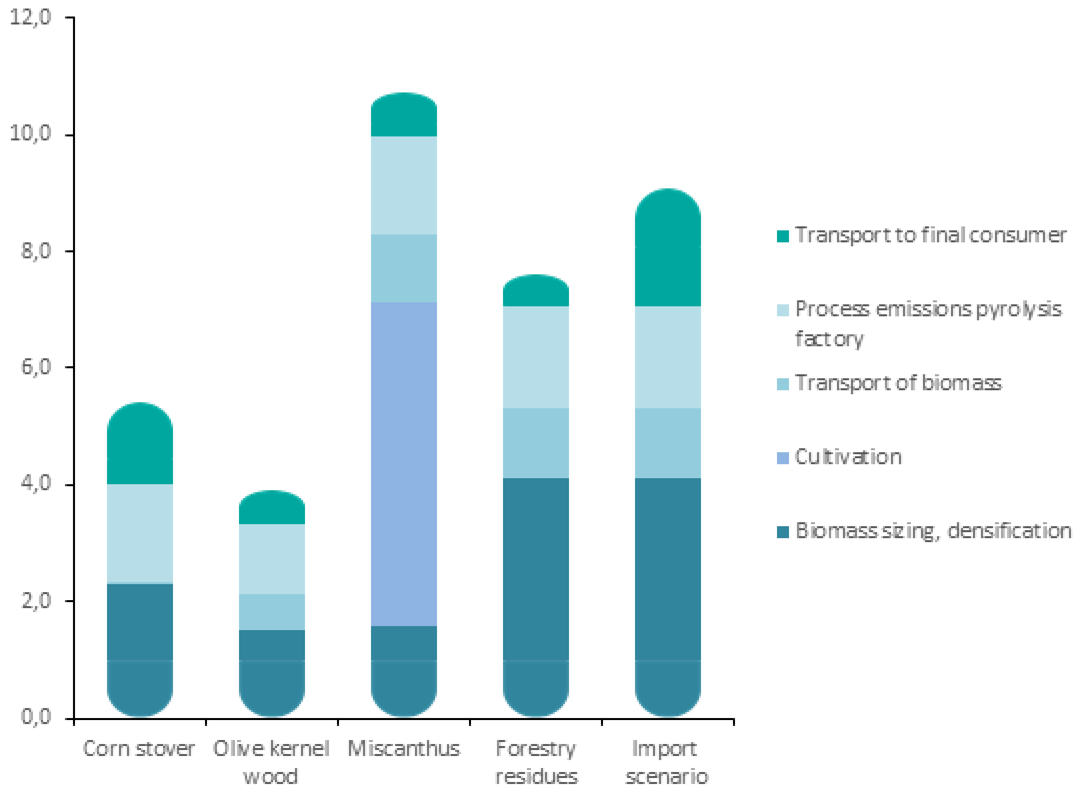

Figure 3: Total emissions from the Smart CHP supply chain from feedstock to end user, considering the energy allocation between pyrolysis oil, steam and electricity (expressed in gCO_2-eq/MJ pyrolysis oil)

2.7 Emission reduction for Smart CHP application

The REDII directive on the promotion of energy utilisation from renewable sources contains requirements to the minimum greenhouse gas emission savings from the use of biofuels (in transportation) and bioliquids (for electricity, heating, and cooling). Only when these requirements are met, these biofuels and bioliquids can be considered for national targets, renewable energy obligations and be eligible for financial support. The following minimum greenhouse gas emission savings must be reached (RED 2018/2001/EU, article 29(10):

a) At least 50% for biofuels and bioliquids produced in installations in operation on or before 5 Oct. 2015;
b) At least 60% for biofuels and bioliquids produced in installations starting operation from 5 October 2015;
c) At least 65% for biofuels and bioliquids produced in installations starting operation after 1 January 2021;
d) At least 70% for electricity, heating, and cooling production from biomass fuels used in installations starting operation after 1 January 2021 and 80% for installations staring operation after 1 January 2026

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An installation shall be considered to be in operation once the physical production of biofuels or bioliquids and of heating and cooling, and electricity for biomass fuels has started.

The relative GHG emission reduction that is achieved by replacing a fossil fuel comparator by a biomass energy carrier is calculated as follows:

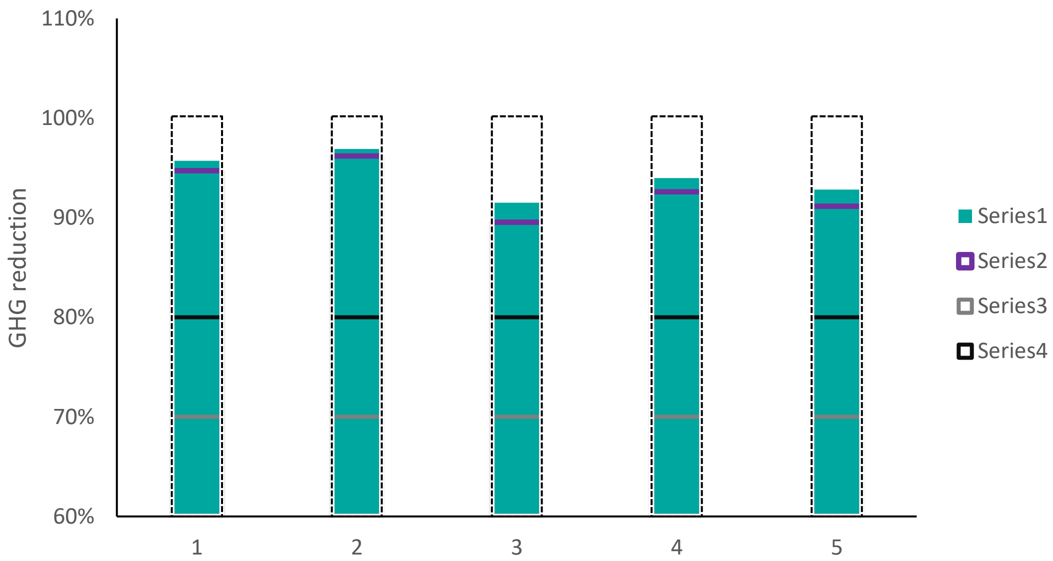
EMISSION SAVINGS = $(E_F - E_B)/E_F$,

Where:

E_B = total emissions from the biofuel or bioliquid; and

E_F = total emissions from the fossil fuel comparator

In the REDII, the fossil fuel comparator of heat and electricity are 80 and 183 gCO_2-eq/MJ, respectively (REDII Annex V, part C, point 19). Furthermore, total greenhouse gas emission from the final energy commodity (i.e. smart CHP) has been calculated according to REDII Annex V, part C, point 1b (iii and iv). Figure 4B



Biomass type	Corn stover	Olive kernel wood	Miscanthus	Forestry residues	Import scenario
Smart CHP electricity (50 km)	95%	96%	90%	93%	91%
Smart CHP heat (50 km)	96%	97%	92%	94%	93%
Smart CHP electricity (150 km)	94%	95%	89%	92%	90%
Smart CHP heat (150 km)	96%	96%	91%	93%	92%

Figure 4: Emission reduction of all five Smart CHP supply chains. A) Emission reduction for heat (green) and electricity (purple) compared to fossil fuel comparators of heat and electricity, assuming minimal FPBO transportation distance. The grey line shows the emission reduction target for installations starting operation after 1 January 2021, and the black line shows the emission reduction target for installations starting operation after 1 January 2026. B) All emission reduction values for both minimum and maximum transportation range.

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shows that the resulting emission reduction values of all Smart CHP supply chains are in the order of 89% to 97%. For the minimum FPBO transportation distance of 50 km, a graph is presented (Figure 4A) that shows both GHG emission savings targets laid out in REDII and the actual savings which are calculated using REDII methodology. Here, it is illustrated that the calculated GHG emission savings exceeds the 2021 target of 70% as well as the 2026 target of 80% required for solid and gaseous biomass.

2.8 Conclusion

It is concluded that all five Smart CHP supply chains from feedstock to end-user meet the minimum emission reduction requirements. This is important because it indicates a ground-level of sustainability. Whether this holds true when, for instance, environmental human health and fossil resources depletion related impacts are included will be further evaluated in the life cycle assessment that is part of Deliverable D5.2.

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3. Other RED II sustainability criteria

3.1 Introduction

In this section the non-GHG related RED II sustainability criteria are assessed. Biofuels, bioliquids and biomass fuels produced from waste and residues, other than agricultural, aquaculture, fisheries and forestry residues, are required to fulfil only the greenhouse gas emissions saving criteria.

- *Residue* means residue' means *a substance that is not the end product(s) that a production process directly seeks to produce; it is not a primary aim of the production process and the process has not been deliberately modified to produce it*.
- Agricultural, aquaculture, fisheries and forestry residues' means *residues that are directly generated by agriculture, aquaculture, fisheries and forestry and that do not include residues from related industries or processing.*

Table 7 shows that only olive kernel wood as being a processing residue is exempted from the non-GHG RED II sustainability criteria. The other biomass types, i.e. corn stover, miscanthus and forestry residues (either used in Sweden or imported to the Netherlands), have to meet the non GHG criteria as presented in this chapter.

Table 7: Overview of applicability of non-GHG RED II criteria to selected biomass types

Biomass type	Does is classify as residue following RED II?	Does is classify as agricultural, aquaculture, fisheries and forestry residues?	Biomass needs to meet the non GHG RED II sustainability criteria?
Corn stover	Yes	Yes	Yes
Olive kernel wood	Yes	No	No
Miscanthus	No	Not applicable	Yes
Forestry residues	Yes	Yes	Yes

Transposition from RED I to RED II

While only minor changes to the GHG emission calculation method have been applied, the RED II sustainability criteria for the other sustainability schemes have been revised more substantially. Moreover, under the RED II the EU sustainability criteria are extended to cover biomass for heating and cooling and power generation. Member States are required to transpose the new rules by 30 June 2021.

Currently, voluntary schemes only certify following the RED I sustainability criteria. The Commission plans to adopt a number of regulations to provide guidance on the implementation of the new sustainability criteria and to update the EU rules for voluntary schemes. Existing voluntary schemes recognized by the Commission will be required to adjust their certification approaches to the new rules. The Commission plans to start the process of recognition of the voluntary schemes for covering the revised sustainability criteria during the first half of 2020[5].

[5] https://ec.europa.eu/energy/en/topics/renewable-energy/biofuels/voluntary-schemes#content-heading-0

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3.2 Soil quality and soil carbon

Following RED II, Article 29(2) *Biofuels, bioliquids and biomass fuels produced from waste and residues derived not from forestry but from agricultural land shall be taken into account […] only where operators or national authorities have monitoring or management plans in place in order to address the impacts on soil quality and soil carbon.*

Information about how those impacts are monitored and managed shall be reported pursuant to Article 30(3). Since voluntary scheme have not been adjusted to RED II yet, it is not known how this sustainability criterion will be dealt with.

3.3 Biodiversity

The RED II protects biodiversity by excluding primary forests, nature protection areas and highly biodiverse grassland as areas for agricultural biomass production to be used for biofuels production. For forest biomass a broader set of sustainability criteria has been developed, including legality of harvesting, forest regeneration, protection of high conservation value areas, minimising harvest impacts on soil & biodiversity, and avoiding that harvest exceeds the long-term production capacity of the forest.

Bioliquids produced from agricultural biomass

Following RED II, article 29(3) *Biofuels, bioliquids and biomass fuels produced from agricultural biomass […] shall not be made from raw material obtained from land with a high biodiversity value, namely land that had one of the following statuses in or after January 2008, whether or not the land continues to have that status:*

(a) primary forest and other wooded land, namely forest and other wooded land of native species, where there is no clearly visible indication of human activity and the ecological processes are not significantly disturbed;

(b) highly biodiverse forest and other wooded land which is species-rich and not degraded, or has been identified as being highly biodiverse by the relevant competent authority, unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;

(c) areas designated:

(i) by law or by the relevant competent authority for nature protection purposes; or

(ii) for the protection of rare, threatened or endangered ecosystems or species recognised by international agreements or included in lists drawn up by intergovernmental organisations or the International Union for the Conservation of Nature, subject to their recognition in accordance with the first subparagraph of Article 30(4),

unless evidence is provided that the production of that raw material did not interfere with those nature protection purposes;

(d) highly biodiverse grassland spanning more than one hectare that is:

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(i) natural, namely grassland that would remain grassland in the absence of human intervention and that maintains the natural species composition and ecological characteristics and processes; or

(ii) *non-natural, namely grassland that would cease to be grassland in the absence of human intervention and that is species-rich and not degraded and has been identified as being highly biodiverse by the relevant competent authority, unless evidence is provided that the harvesting of the raw material is necessary to preserve its status as highly biodiverse grassland.*

Bioliquids produced from forest biomass

The following RED II sustainability criteria to bioliquids produced from forest biomass (RED II, article 29(6)) have the purpose to minimise the risk of unsustainable forest harvesting. These criteria are supposed to be primarily met by national and sub-national law, but in case such law is not in place, management systems at forest sourcing areas should be in place to ensure that unsustainable forest harvesting is avoided.

Biofuels, bioliquids and biomass fuels produced from forest biomass […] shall meet the following criteria to minimise the risk of using forest biomass derived from unsustainable production:

(a) the country in which forest biomass was harvested has national or sub-national laws applicable in the area of harvest as well as monitoring and enforcement systems in place ensuring:
   (i) the legality of harvesting operations;
   (ii) forest regeneration of harvested areas;
   (iii) that areas designated by international or national law or by the relevant competent authority for nature protection purposes, including in wetlands and peatlands, are protected;
   (iv) that harvesting is carried out considering maintenance of soil quality and biodiversity with the aim of minimising negative impacts; and
   (v) that harvesting maintains or improves the long-term production capacity of the forest;

(b) when evidence referred to in point (a) of this paragraph is not available, the biofuels, bioliquids and biomass fuels produced from forest biomass shall be taken into account for the purposes referred to in points (a), (b) and (c) of the first subparagraph of paragraph 1 if management systems are in place at forest sourcing area level ensuring:
   (i) the legality of harvesting operations;
   (ii) forest regeneration of harvested areas;
   (iii) that areas designated by international or national law or by the relevant competent authority for nature protection purposes, including in wetlands and peatlands, are protected unless evidence is provided that the harvesting of that raw material does not interfere with those nature protection purposes;
   (iv) that harvesting is carried out considering the maintenance of soil quality and biodiversity with the aim of minimising negative impacts; and
   (v) that harvesting maintains or improves the long-term production capacity of the forest.

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3.4 Carbon stock

Bioliquids produced from agricultural biomass

RED II Article 29(4) provides the following criterion to avoid loss of carbon stock: *Biofuels, bioliquids and biomass fuels produced from agricultural biomass […] shall not be made from raw material obtained from land with high-carbon stock, namely land that had one of the following statuses in January 2008 and no longer has that status:*

(a) wetlands, namely land that is covered with or saturated by water permanently or for a significant part of the year;
(b) continuously forested areas, namely land spanning more than one hectare with trees higher than five metres and a canopy cover of more than 30 %, or trees able to reach those thresholds in situ;
(c) 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, unless evidence is provided that the carbon stock of the area before and after conversion is such that, when the methodology laid down in Part C of Annex V is applied, the conditions laid down in paragraph 10 of this Article would be fulfilled.

This paragraph shall not apply if, at the time the raw material was obtained, the land had the same status as it had in January 2008.

Moreover, emissions from drainage of **peatlands** should be avoided (RED II, Article 29(5): *Biofuels, bioliquids and biomass fuels produced from agricultural biomass […] shall not be made from raw material obtained from land that was peatland in January 2008, unless evidence is provided that the cultivation and harvesting of that raw material does not involve drainage of previously undrained soil.*

Bioliquids produced from forest biomass

RED II Article 29(7) requires that LULUCF-sector emissions do not exceed removals, that an accounting system is in place, as well as laws to conserve and enhance carbon stocks and sinks. If such systems and laws are not in place at national level, management systems at forest sourcing area level have to be in place.

Biofuels, bioliquids and biomass fuels produced from forest biomass […] shall meet the following land-use, land-use change and forestry (LULUCF) criteria:

(a) the country or regional economic integration organisation of origin of the forest biomass:
(i) is a Party to the Paris Agreement;
(ii) has submitted a nationally determined contribution (NDC) to the United Nations Framework Convention on Climate Change (UNFCCC), covering emissions and removals from agriculture, forestry and land use which ensures that changes in carbon stock associated with biomass harvest

are accounted towards the country's commitment to reduce or limit greenhouse gas emissions as specified in the NDC; or

(iii) has national or sub-national laws in place, in accordance with Article 5 of the Paris Agreement, applicable in the area of harvest, to conserve and enhance carbon stocks and sinks, and providing evidence that reported LULUCF-sector emissions do not exceed removals;

(b) where evidence referred to in point (a) of this paragraph is not available, the biofuels, bioliquids and biomass fuels produced from forest biomass shall be taken into account […] if management systems are in place at forest sourcing area level to ensure that carbon stocks and sinks levels in the forest are maintained, or strengthened over the long term.

How to prove this?

This will be worked out later as Article 29(8) states that *by 31 January 2021, the Commission shall adopt implementing acts establishing the operational guidance on the evidence for demonstrating compliance with the criteria laid down in Article 29(6) and 29(7)*.

3.5 Conclusion

Olive kernel wood has only to apply to the RED II GHG reduction criteria. Corn stover, forestry residues and miscanthus need to meet the non-GHG sustainability criteria in RED II. At this moment (June 2020) we are in the transition toward implementation of RED II. The European Commission needs to adopt implementing acts establishing operational guidance for demonstrating compliance to the carbon stock criterion by 31 January 2021. Member States are required to transpose the new rules by 30 June 2021. Moreover, the existing voluntary schemes recognized by the Commission need to adjust their certification approaches to the new rules. This means that an assessment of the sustainability criteria at a detailed level is not possible at present. However, in general, no RED II sustainability criteria have been identified, which would block the use of corn stover, forestry residue and miscanthus.

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4. Other sustainability topics

4.1 Carbon debt

In the current European renewable energy policy framework, biomass used for energy and transport is considered as a carbon neutral source. However, if a tree is harvested, it will take many years before a new tree is grown up, creating a temporary carbon debt. Moreover, if biomass is combusted instead of natural gas, the direct CO_2-emissions are even higher because wood is a more carbon intensive fuel than natural gas. The payback time of this carbon debt depends on the speed at which the biomass regrows and is longer when old slowly growing trees are combusted than when short rotation coppice is used. Therefore, although bioenergy is carbon neutral on the long term, on the short term this is not necessarily the case. NGOs have put the issue of carbon debt on the agenda especially in relation to the use of whole trees in wood pellet production for co-combustion in coal power plants. It would mainly affect woody biomass value chains, in our report the case of the forestry residues.

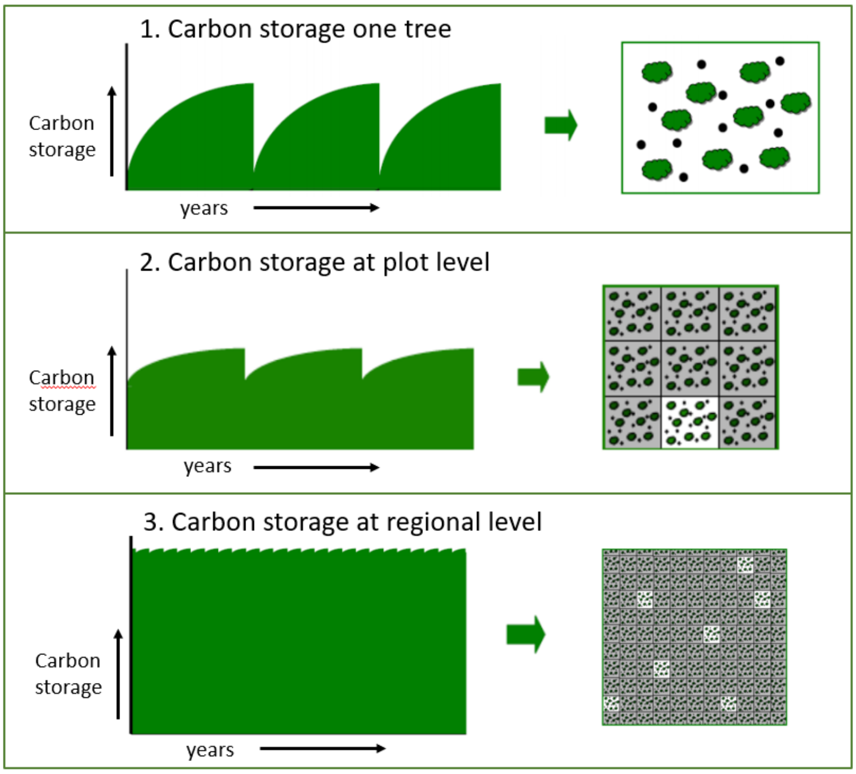

Figure 5: Carbon storage at the level of tree, plot and region. Source: CE (Delft 2013)[6], adapted by BTG.

[6] CE Delft (2014) Inzichtelijk maken van maatschappelijke risico's van het opnemen van carbon debt vereisten. For Rijksdienst voor Ondernemend Nederland (RVO) and the Ministry of Infrastructure and Environment.

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However, the issue of carbon debt requires further scrutiny: at the level of a single tree carbon debt might occur, but this is not necessarily the case if a larger plot or a whole forest is considered. If for instance a forest's volume grows with 2% per year, it is possible to harvest 2% of the trees while the forest's carbon pool remains intact. See the illustration in Figure 5.

Table 8: Carbon balance of EU28.

Table ES. 5 Overview of EU-28 GHG emissions (in million tonnes CO_2-equivalent) in the main source and sink categories for the period 1990 to 2016

GHG SOURCE AND SINK	1990	1995	2000	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
1. Energy	4 355	4 088	4 022	4 123	4 121	4 066	3 985	3 701	3 800	3 651	3 607	3 518	3 339	3 375	3 352
2. Industrial Processes	518	499	457	467	466	478	453	379	396	392	379	378	384	379	377
3. Agriculture	543	473	459	435	431	434	431	426	421	421	419	422	429	430	431
4. LULUCF	-250	-275	-305	-312	-325	-289	-324	-325	-317	-306	-306	-312	-310	-307	-291
5. Waste	236	244	229	200	194	188	179	173	166	161	157	150	144	141	139
6. Other	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
indirect CO_2 emissions	4	4	3	2	2	2	2	2	2	2	2	2	2	2	1
Total (with net CO_2 emissions/removals)	**5 407**	**5 033**	**4 864**	**4 915**	**4 890**	**4 879**	**4 727**	**4 355**	**4 469**	**4 321**	**4 259**	**4 158**	**3 988**	**4 019**	**4 009**
Total (without LULUCF)	**5 657**	**5 307**	**5 169**	**5 227**	**5 215**	**5 168**	**5 051**	**4 680**	**4 785**	**4 627**	**4 564**	**4 469**	**4 298**	**4 327**	**4 300**

Source: European NIR (2019) https://unfccc.int/documents/65886

Further evidence that carbon debt is not an issue at European level can be obtained from National Inventory Reports (NIRs)[7], in which the carbon balance at level of countries and EU are presented. The NIR of EU 28 (See Table 8) shows that the carbon stock level in European forests is stable. LULUCF means Land Use, Land-Use Change and Forestry and shows the storage of carbon in plants and forests. The table shows that the fossil energy sector is the largest source of greenhouse gas emissions (expressed in CO_2-equivalents). It would not make sense not to reduce these fossil emissions by renewable energy produced from solar wind and bioenergy.

4.2 Indirect land use change

4.2.1 Introduction

When pasture or agricultural land that was previously destined for food, feed and fibre production is diverted to biofuel/bioenergy/bio-based products production, the existing demand will need to be satisfied either through intensification of the current production or by bringing non-agricultural land into production elsewhere. The latter case represents indirect land-use change (ILUC) and could potentially lead to significant greenhouse emissions, if it involves the conversion of high carbon stock land.

[7] See https://unfccc.int/process-and-meetings/transparency-and-reporting/reporting-and-review-under-the-convention/greenhouse-gas-inventories-annex-i-parties/submissions/national-inventory-submissions-2018

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4.2.2 ILUC in the RED and RED II

It is impossible to trace the direct relation between the use of land plot A and indirect conversion of land plot B. However, generic "ILUC factors" have been developed that put a greenhouse gas emission reduction penalty on certain crops. The question whether it is possible to quantify ILUC factors with sufficient accuracy is still subject to scientific debate. Nevertheless, in the ILUC proposal of the European Commission (COM(2012)595), ILUC emissions were introduced for cereals and other starch rich crops, sugars and oil crops. Especially the ILUC factor of oil crops of (55 gCO_{2eq}/MJ) would have shrunk the reduction of greenhouse gas emissions achieved by biodiesel below the threshold of 35% emission reduction, directly threatening the biodiesel industry. However, the finally approved ILUC Directive (2015/1513) contains only a reporting obligation for Member States and the Commission, and biofuel producers do not have to take into account ILUC factors in their GHG reduction calculation.

Table 9: Overview of selected feedstocks and their listing under RED II Annex IX

Feedstock investigated in SmartCHP	**Listed under RED Annex IX, category:**
Corn stover	(n) Cobs cleaned of kernels of corn (e) Straw
Forestry residues	(o) Biomass fraction of wastes and residues from forestry and forest-based industries, namely, bark, branches, pre-commercial thinnings, leaves, needles, tree tops, saw dust, cutter shavings, black liquor, brown liquor, fibre sludge, lignin and tall oil; (q) other lignocellulosic materials[a)] except saw logs and veneer logs
Olive kernel wood	(m) husks (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 [RED Annex IX]
Miscanthus	(p) Other non-food cellulosic material[b)]

[a)] In the RED II 'ligno-cellulosic material' means material composed of lignin, cellulose and hemicellulose, such as biomass sourced from forests, woody energy crops and forest-based industries' residues and wastes;

[b)] 'non-food cellulosic material' means feedstock mainly composed of cellulose and hemicellulose, and having a lower lignin content than ligno-cellulosic material, including food and feed crop residues, such as straw, stover, husks and shells; grassy energy crops with a low starch content, such as ryegrass, switchgrass, miscanthus, giant cane; cover crops before and after main crops; ley crops; industrial residues, including from food and feed crops after vegetal oils, sugars, starches and protein have been extracted; and material from biowaste, where ley and cover crops are understood to be temporary, short-term sown pastures comprising grass-legume mixture with a low starch content to obtain fodder for livestock and improve soil fertility for obtaining higher yields of arable main crops;

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ILUC is especially relevant for biofuels made of sugar, starch and especially oil crops. Pyrolysis oil is a bioliquid made of lignocellulosic biomass. The RED II has a list (Annex IX) of feedstocks for the production of advanced biofuels that, contrary to first generation biofuels from agricultural sugar and oil crops, are supposed to have low or no indirect land use impacts. Table 9 shows that all investigated feedstocks are found in Annex IX, which indicates these are low ILUC risk feedstocks.

4.2.3 ILUC in biomass sustainability schemes

RSB, Better Biomass (NTA8080-1:2015) and ISCC-PLUS have not implemented ILUC factors for agricultural biomass to compensate for indirect emissions elsewhere, as was proposed in EC proposal COM(2012)595 for the "ILUC Directive". RSB and NTA8080 stress the importance of this matter in their documentation but see no possibilities to apply ILUC factors on farm level. Instead, RSB and NTA8080 promote low ILUC biomass through the use of a "Low Indirect Impact Biofuels" (LIIB) approach that is being developed by WWF, Ecofys and EPFL.

Better Biomass

In the Better Biomass scheme the criterion on low ILUC biomass is stated in the following way.

Box 1: Low ILUC in Better Biomass

If the organization opts to or is required to market its biomass as 'ILUC low risk', it shall reduce the risk of ILUC in the biomass chain by choosing one or more of the following possible solutions:

1) growing biomass on previously unused land;
   NOTE 1: Unused land is taken to mean land that does not provide for the delivery of services, i.e. products
   obtained from ecosystems, including food, fibres, fuel, natural medicines, water and wood. Unused land is also designated as fallow land, degraded land, marginal land or abandoned land.
2) additional productivity increase, on top of the trend line, by actions such as:
   - shortening the period that arable land is left fallow;
   - intensifying the use of grassland;
   - increasing the harvest frequency on arable land;

   NOTE 2: The harvest frequency is taken to mean the average number of crops that is harvested on a plot of arable land. The harvest frequency is represented by the multiple cropping index (Beets, 1982).
3) integrating existing agriculture or forestry with additional biomass production;
   NOTE 3: For example, stock farming combined with sugarcane production, with the bagasse serving as animal feed, additional crops in double cultivation with existing crops, etc.
4) use of waste and residual flows that had no other application before.

The organization shall visualize the measures taken in order to implement this solution or these solutions using the most recent version of the 'Low Indirect Impacts Biofuels' (LIIB) methodology or an analogous method. 1 January 2015 shall be kept as the reference date.

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NOTE: The LIIB method is available at http://www.ecofys.com/en/project/low-indirect-impact-biofuel-methodology. Other methods that provide an understanding of the 'ILUC low risk' biomass in a comparable manner can be made available in the future.

Within Better Biomass the "ILUC low risk" option is only applicable to primary biomass producers, not to collectors of primary or non-primary residual flows (see NTA8080-1:2015 Annex A)[8]. This means that only corn stover and miscanthus can obtain the "ILUC low risk" label.

RSB

RSB has used the LIIB methodology as a basis for the development of RSB low indirect land use criteria for biomass on unused land, yield increase on the same land and for waste and residues (RSB 2015)[9]. Biomass waste and residues can be regarded low ILUC risk if (1) the biomass used for biofuel or biomaterial production is eligible as a waste or a residue under RSB-STD-01-010 (Global) or RSB-STD-11-001-01-010 (EU RED) (RSB 2016)[10] requirements and should meet criteria (2), or (3) and (4):

2. The waste/residue is generally discarded for landfilling or incineration in the region where it is generated. This means that the waste/residue is available for use as biofuel/biomaterial feedstock in a given region, i.e. there is no other use being made of it.
3. The use of this waste/residue does not result in any indirect increase in greenhouse gas emissions, for example for electricity (co)generation, combined heat and power, or as a fertilizer or other soil input and/or that its diversion to produce biofuels or biomaterials does not result in the use of fossil combustible in replacement.
4. The use of this waste/residue does not result in any displacement of land use. For example, you shall demonstrate that this waste/residue was not used previously as food, feed, fibre, or any other use requiring arable land.

So, in fact both indirect land use and displaced use are taken into account to obtain a low ILUC risk label.

*Error! Reference source not found.*Table 10 shows the results of the initial application of these criteria to the SmartCHP residual feedstocks.

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[8] Moreover, according the LIIB methodology (van de Staaij, et. Al 2012), the sustainability scheme owner should have a positive list of "end-of-life products with a low risk of unwanted indirect impacts". This list is not available in NTA 8080-1:2015.

[9] RSB (2015) RSB Low ILUC risk biomass criteria and compliance indicators, RSB reference code: [RSB-STD-04-001 (Version 0.3)].

[10] RSB (2016) Consolidated RSB EU RED Standard for certification of biofuels based on waste and residues, RSB reference code: [RSB-STD-11-001-01-010 (Version 1.0)]

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Table 10: Initial application of RSB low indirect land use criteria for waste and residues to the selected biomass types. Miscanthus was not included in this table because it is not a residue.

Feedstock investigated in SmartCH4 Project	Country	Listed as waste or residue	Criterion 2: Generally discarded for landfilling or incineration?	Criterion 3: Indirect GHG emissions (displacement bioenergy or soil application)?	Criterion 4: Displacement of land use (use as food, feed, fibre)	Result: Low ILUC feedstock according to RSB likely?
Corn stover	RO	Yes	No	No	Yes	No
Softwood forestry residues	SE	Yes	No	yes	No	No
Olive kernel wood	GR	Yes	No	yes	No	No

Conclusion

All selected feedstocks are part of Annex IX of the RED, which is a list of feedstocks for low ILUC impact second generation biofuels production. The SmartCHP feedstocks are generally not landfilled or incinerated without energy generation, but usually have a function as energy source for bioenergy production. Corn stover can be used as fodder. Thus, using the feedstocks for SmartCHP will have displacement impacts and indirect emissions.

4.3 Cascading use & circular economy

4.3.1 Introduction

Literature includes a wide range of different definitions of the term cascading use (Vis, Mantau, Allen, 2016). In the first place the term cascading use refers to subsequent material uses of biomass followed by final conversion into energy. Secondly, it is used in relation to biorefineries, stressing the possibilities to produce multiple products out of one biomass source; this is also referred to as coproduction. Finally, the term is used to express that biomass should be used in such way that it creates the highest value, usually economic value added, but this could be supplemented with indicators for social and environmental value. Following (Vis, Mantau, Allen, 2016), in this report only the subsequent material use of biomass will be called cascading use.

4.3.2 Cascading use & circular economy in RED II

Cascading use of biomass or following circular economy principles is not a direct sustainability criterion in the RED II. However, according to RED II article 28.6, the European Commission has to take into account *the principles of the circular economy and of the waste hierarchy established in Directive 2008/98/EC* in their biannual evaluation to determine whether new feedstocks could be added to the list in Annex IX. The RED II does not work out the principles of circular economy in any more detail. According to SWD (2019) 90 on the implementation of the Circular

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Economy Action Plan[11] this addresses the risk of conflicting use of biomass resources between energy and non-energy sectors and of creating financial incentives that would undermine the separate collection obligations set out in the Waste Framework Directive.

Directive 2008/98/EC, also known as the Waste Framework Directive Article 4, describes the waste hierarchy. It states that the following waste hierarchy shall apply as a priority order in waste prevention and management legislation and policy:

(a) prevention;

(b) preparing for re-use;

(c) recycling;

(d) other recovery, e.g. energy recovery; and

(e) disposal.

These steps are further refined in waste management plans at national level.

Originally the waste hierarchy has been set up for wastes that haven been through the product phase and are now to be discarded as waste, like demolition wood. Miscanthus is not waste and thus exempted from waste law. Following the waste hierarchy, residues should be avoided as much as possible. Re-use and recycling options could be taken as material re-use and recycling. These options are limited for olive kernel wood. Depending on the quality forestry residues could be used in the paper industry. If this is the case, competition with material sector does exist. This, however, really depends on the quality of the wood chips, forestry residues containing bark are normally not useful in paper production. Corn stover could be used as fodder, which can be regarded as a potential sustainability risk. It is worth to check the origin and use of corn stover in Romania in more detail in the next stage of the project. This may be not necessary for compliance of the feedstocks with RED II as all selected feedstocks are already part of Annex IX but could be relevant in the broader sustainability discussion.

4.3.3 Cascading use and circular economy in biomass sustainability schemes

Cascading use has a strong link with the application, but less with the production of biomass and is therefore not covered well in existing sustainability schemes. However, cascading is covered in the NTA8080-1:2015 standard in the form of a reporting obligation on resource efficient use of biomass. The organisation that seeks certification has to describe the choice of the used biomass and measures that are taken to use the biomass in the most resource efficient way possible. Other schemes do not cover cascading use yet. The NTA8080 criterion on cascading use is described as follows:

In many events, biomass flows can be used for different applications, for example as raw material for food and materials and as fuel for energy production. The use

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[11] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52019SC0090&from=EN

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of biomass for energy should not displace its application in food and materials. Biomass should be used in the most raw materials-efficient way possible throughout its entire lifecycle. To achieve this, the organization shall provide an understanding of the efficient use of biomass by:

a) describing the choice of the raw materials used, justifying that use for food and materials is not self-evident, based on:

- *environmental considerations;*
- *economic considerations;*
- *logistic considerations;*

NOTE The degree of justification of the choice of the raw material used should be proportional to the extent of the business operations regarding such material.

b) describe which measures have been taken in order to use and to continue to use biomass as raw materials-efficiently as possible (cascading).

4.3.4 Biomass in the Circular Economy Action Plan

The Commission Staff Working Document on the implementation of the Circular Economy Action Plan addresses the role of biomass in the circular economy by three EU actions:

- Provisions on circular economy and waste hierarchy as discussed above;
- The updated bioeconomy strategy; and
- Guidance on cascading use of biomass.

The latter is discussed below. The non-binding EU *"Guidance on cascading use of biomass with selected good practice examples on woody biomass"*[12] defines five Guiding Principles:

1. *Sustainability*: Any cascading solution to promote the highest economic added value must consider its impact on the other two pillars of sustainability: the social and environmental aspects.
2. *Resource efficiency*: Promote resource efficiency by focusing on uses with the highest economic added value and favouring a market-based approach.
3. *Circularity in every stream and at every step*: keeping in the loop all streams of woody biomass put to different resource-efficient uses in line with the previous principle.
4. *New products and new markets*: Stimulate uses of woody biomass with high added value by making new products and new markets.
5. *Subsidiarity:* Cascading should respect not only national contexts but also regional and local ones in assessing the most economically viable use of biomass.

In this guidance various innovative often material applications of wood are presented and connected to the guidance principles. The production of pyrolysis oil from biomass fits in the picture that various application, from energy to chemicals and products are possible. The guidance document did not result in the identification of sustainability risks for the selected biomass types.

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[12] https://op.europa.eu/en/publication-detail/-/publication/9b823034-ebad-11e8-b690-01aa75ed71a1/language-en/format-PDF/source-80148793

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5. Conclusions and recommendations

The following conclusions and recommendations are made from the RED GHG emission reduction calculation, the assessment of RED non GHG sustainability criteria and the sustainability risk assessment:

- Results show that the emission reduction values of all Smart CHP supply chains are in the order of 89% to 97%. This indicates that the calculated GHG emission savings exceeds the required target of 70% emission reduction for electricity, heating, and cooling production from biomass fuels used in installations starting operation after 1 January 2021 and 80% for installations staring operation after 1 January 2026 as laid out in article 29(10) of the RED II. Therefore, the energy produced from all Smart CHP supply chains can be accounted for national renewable energy targets and are eligible for financial support.
- Olive kernel wood has to comply to the RED II greenhouse gas emission reduction criteria only. Corn stover, forestry residues and miscanthus need to meet the RED II non-GHG sustainability criteria as well. It is expected that all selected feedstocks are able to meet these sustainability criteria regarding e.g. soil quality and soil carbon, biodiversity and carbon stocks. It has to be observed that at the time of writing, the RED II is still in the process of implementation. It is recommended to check the implementing acts which are not published yet at the time of writing and the still to be updated voluntary sustainability schemes at a later stage to confirm compliance with RED II.
- The National Inventory Reports (NIRs), in which the carbon balance at level of countries and EU as a whole are presented, show that the European forests have a stable carbon stock. Despite these facts, in some Member States the public opinion regarding the use of forest biomass is very negative. It is recommended to take the issue of carbon debt into account in the further work on public perception.
- All selected biomass types are included in RED II Annex IX of low Indirect Land Use (ILUC) risk biomass types, which indicates that the selected feedstocks are low ILUC risk feedstocks. The feedstocks would not qualify as "low ILUC" feedstock following the very strict LIIB methodology as applied by Roundtable on Sustainable Biomaterials, because the selected feedstocks are generally not discarded for landfill and incineration but already used for energy
- The EU "*Guidance on cascading use of biomass with selected good practice examples on woody biomass* did not result in the identification of sustainability risks for the selected biomass types. The production of pyrolysis oil from biomass fits in the picture that various application, from energy to chemicals and products from low value residues are possible.

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