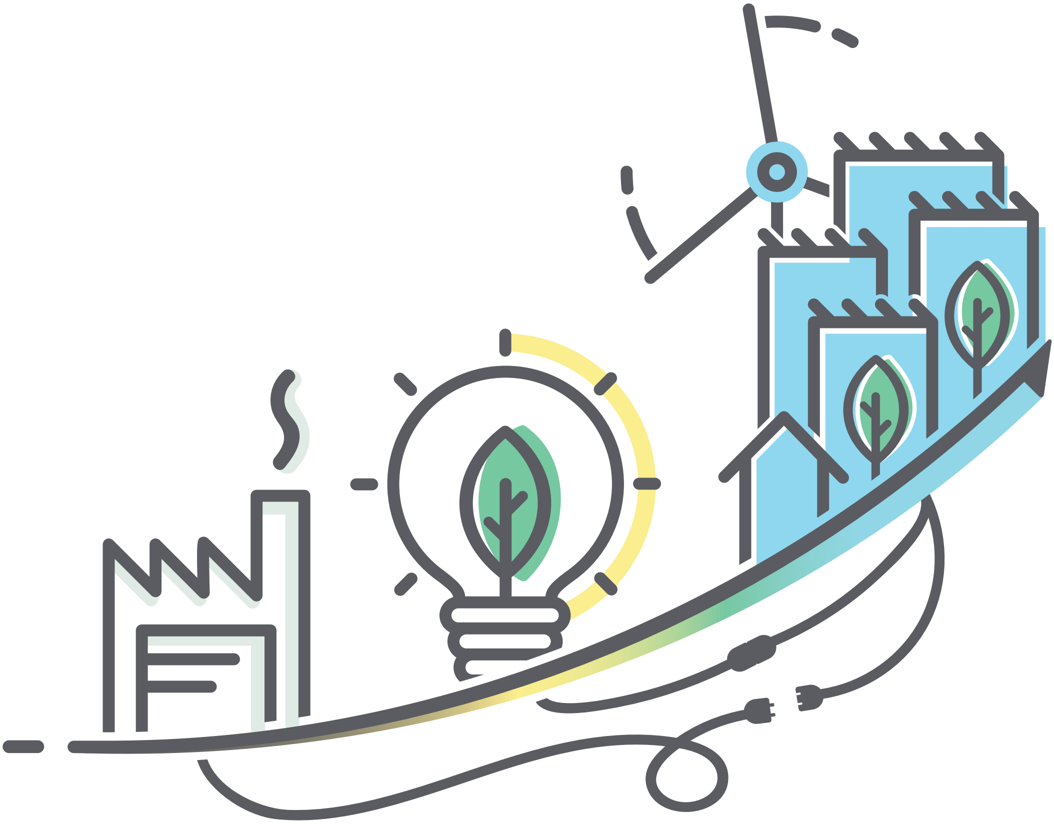
SUSTAINABLE BIOENERGY PATHWAYS

Conditions to move forward



Thuy MAI-MOULIN

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"The clear and present danger of climate change means we cannot burn our way to prosperity. We already rely too heavily on fossil fuels. We need to find a new, sustainable path to the future we want. We need a clean industrial revolution"

Ban Ki-moon

"Often, sustainability is discussed only in the context of energy. Energy sustainability is essential - but the word has a much broader meaning. It means long-term thinking about how we manage our businesses, invest in social spending, and plan for the future. This requires vision and leadership, and it requires citizen engagement"

Joe Kaeser

"Everything is figureoutable"

Marie Forleo

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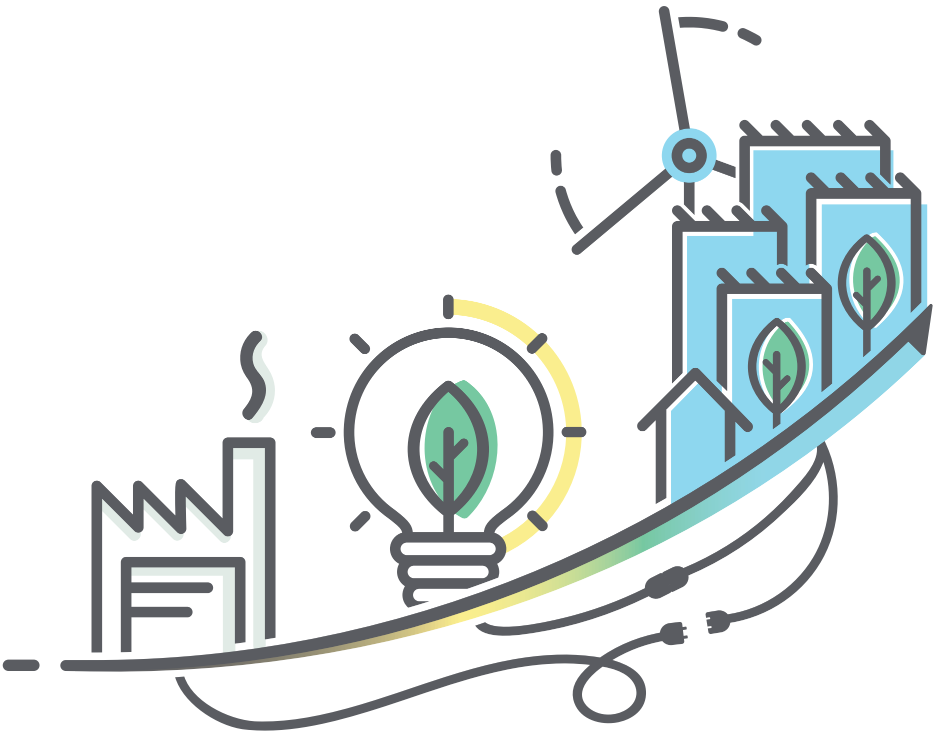
ABBREVIATION AND UNIT

AFOLU	Agriculture, Forestry And Other Land Use
BAU	Business As Usual Scenario
BECCS	Bioenergy With Carbon Capture and Storage
BEIS	Department for Business, Energy and Industrial Strategy of the United Kingdom
BMPs	Best Management Practices
BSvs	Biomass Biofuels voluntary scheme
CAP	Common Agricultural Policy
C_D	Total Production Cost of Biomass
C_H	Cost of Handling and Storage
C_P	Cost of Feedstock Production
C_{Pt}	Cost of Pre-Treatment
C_{Tdf}	Cost of Domestic Transport (Fields to Pre-Treatment Facilities)
C_{Tdp}	Cost of domestic transport from pre-treatment facilities to export location,
C_{Ti}	Cost of international transport from export locations to Rotterdam port
CfD	Contracts for Difference of the United Kingdom
CHP	Combined Heating And Power Plant
CoC	Chain of Custody
CY	Pelletising Capacity
E	Total GHG Emissions
E_{ec}	Emissions Of Cultivation (Only for Energy Crops)
E_s	Emissions of Nutrient Replacement
E_p	Emissions From Pre-Treatment
E_{dt}	Emissions From Domestic Transport
E_{it}	Emissions From Intercontinental Transport to Rotterdam
EC	European Commission
EU	European Union
EUTR	European Timber Regulation
ETS	Emissions Trading System

FAO	Food and Agriculture Organisation of the United Nations
FiT	Feed-In Tariff
FMU	Forest Management Unit
FSC	Forest Stewardship Council
GBEP	Global Biomass Partnership
GC	Belgian Green Certificates
GHG	Greenhouse Gas emissions
GIS	Geographical Information System
GTAS	Gafta Trade Assurance Scheme
HE	High Export Scenario
HVO	HVO Verification Scheme
IAMs	Integrated Assessment Models
(I)LUC	(Indirect) Land Use Change
IPCC	Intergovernmental Panel on Climate Change
ISCC	International Sustainability and Carbon Certification
IA	Danish Industry Agreement
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature
KZR	KZR INIG System
LCA	Life Cycle Assessment
LD	Local Demand
LHV	Low Heating Value
LIIB	The Low Indirect Impact Biofuels
LULUCF	Land Use, Land Use Change and Forestry
Mt	Million tonnes
MS	Member State
NGO	Non-Governmental Organisation
NUT	Nomenclature of Territorial Units
PEFC	Programme for the Endorsement of Forest Certification
RBA	Risk Based Approach
RED	Renewable Energy Directive
Red Tractor	Red Tractor Farm Assurance Combinable Crops & Sugar Beet Scheme
RFRs	Renewable Fuels Regulations

RFS	Renewable Fuel Standard
RHI	Renewable Heat Incentive of the United Kingdom
PJ	Petajoule
P_E	Export Potential
P_T	Technical Potential
P_S	Sustainable Potential
P_{SS}	Sustainable Surplus Potential
PV	Solar Photovoltaics
RO	Renewable Obligation Order of the United Kingdom
RPR	Residue-To-Product Ratios
RSB	Roundtable on Sustainable Biomaterials
RSBO	Roundtable on Sustainable Palm Oil
RTFO	Renewable Transport Fuel Obligation Order of the United Kingdom
RTRS	Round Table on Responsible Soy
RVO	Netherlands Enterprise Agency
SBP	Sustainable Biomass Program
SDGs	Sustainable Development Goals
SDE+	Dutch Stimulation of Sustainable Energy Production
SFI	Fibre Sourcing Standard
SFM	Sustainable Forest Management
SI	Supplementary Information
SOC	Soil Organic Carbon
SRF	Sustainable Recovery Factor
SQC	Scottish Quality Farm Assured Combinable Crops
Trade Assurance	Trade Assurance Scheme for Combinable Crops
UFAS	Universal Feed Assurance Scheme
UK	United Kingdom
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
US	United States
WWF	World Wide Fund for Nature
WTO	World Trade Organisation



1

Introduction

1.1. GLOBAL BIOENERGY DEVELOPMENT

In the modern age, natural resources have been rapidly exploited and fossil fuels have become dominant in the global energy system.[1] Rapid consumption of natural resources and fossil fuels has led to negative impacts including climate change and biodiversity loss.[2] The current global energy supply is still largely based on fossil resources including coal, oil, and natural gas, and dominates global anthropogenic greenhouse gas (GHG) emissions: nearly 68% of human induced GHG emissions are caused by CO_2 emissions from the combustion or industrial use of fossil fuels.[3] Agriculture, forestry and other land use (AFOLU) is the second largest driver of human induced climate change representing about 23% of total human induced GHG emissions over the period 2007 to 2016.[4,a] In 2015, the Paris Agreement was adopted at the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC).[5] The long term goal of the Paris Agreement is to keep global warming levels to well below 2°C and pursues efforts to limit global temperature increase to maximum 1.5°C above pre-industrial levels. The goal therefore requires structural changes in the global energy system, as well as in forestry, agriculture and other land uses.

The main options to mitigate GHG emissions in the energy sector cover energy efficiency measures, and transition from a fossil energy system to a renewable energy system including wind, solar photovoltaics (PV), geothermal energy, and bioenergy. Biomass used for energy purposes, bioenergy, has multiple roles in the energy transition. It is the largest source of renewable energy, contributing about 9.5% (56 EJ) to global final energy supply in 2017.[6] More than half of biomass is still exploited for traditional bioenergy uses of inefficient heating and cooking applications. However, this traditional use of bioenergy is steadily declining; whereas the deployment of modern bioenergy, including efficient heating, electricity and transport biofuels has grown rapidly in the past two decades. Today, modern bioenergy contributes to more than half of total renewable energy generation, and is still roughly four times larger than the combined energy generated by wind and PV.[7]

The rapid development of modern bioenergy was mainly driven by the promotion of renewable energy under various national and international policies. In the European

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a *the remaining sources of GHG emissions, among others include CH_4, N_2O and fluorinated gas emissions from other sectors than agriculture and forestry*

Union (EU), renewable energy targets have been set to mitigate climate change, increase the share of renewable energy, and ensure a secure and sustainable energy supply. In the early 2000s, EU policies started the promotion of biofuels and other renewable fuels for the transport sector.[8,9] In 2009, the Renewable Energy Directive (RED I) was adopted, establishing binding national specific targets by 2020 for renewable energy.[10] Currently bioenergy is the largest renewable energy source in the EU contributing to 65% of renewable energy supply,[11] making the EU the world leading region of bioenergy production and consumption.[12] In North America, the Renewable Fuel Standard in the United States (US) and the Renewable Fuels Regulations in Canada have also stimulated a high target for biofuel production.[13,14]

The transition from local, traditional bioenergy to modern bioenergy also resulted in larger distances between locations of biomass supply and bioenergy demand. Furthermore, differences between countries that have abundant biomass supply and countries that have limited available biomass resources have spurred the development of international biomass trade of solid biomass and liquid biofuels.[15–17] In particular international trade of wood pellets, ethanol and biodiesel have increased substantially. The EU is still the main importing region, but markets in Asia are also developing.[17] Bioenergy policies in Japan and Republic of Korea have triggered an increased bioenergy consumption which is largely fulfilled by import of solid biomass for bioenergy production.[18,19]

The future development of bioenergy is highly uncertain and varies substantially amongst different model projections and between different scenario conditions. These include, amongst others, the set climate targets and the availability of advanced bioenergy technologies such as biomass with CCS (BECCS), advanced biofuels and bio-based materials. Nevertheless, bioenergy is almost consistently projected to play a large role in future climate mitigation scenarios along other renewable energy options, carbon sequestration, and energy saving measures.[20] A review of future projections of global bioenergy use show that primary bioenergy could increase to 100 – 300 EJ by 2050.[21] The Intergovernmental Panel on Climate Change (IPCC) estimated that bioenergy could contribute between 40 to 310 EJ by 2050 in the transition to the 1.5^{o}C pathway.[22] A recent comparison of eleven Integrated Assessment models (IAMs) showed that bioenergy demand will likely exceed 100 EJ by 2050 when a 2^{o}C temperature increase climate target is pursued, and likely increase above 150 EJ to up to 280 EJ if a maximum temperature rise of 1.5°C compared to preindustrial levels is aimed for.[20] As a consequence, International biomass trade from regions of abundant biomass resources to regions of high biomass demand will likely increase in the future to meet the increasing global biomass demand for bioenergy.[23]

Also within the EU, bioenergy is expected to remain a key component in the European energy mix, and it is considered having important roles in the 2050 long-term strategy.[24] The EU bioenergy demand is projected to increase from 5.7 EJ in 2015 to 7.9 to 10.5 EJ by 2050. This demand also shows a sharp decline in residential use of bioenergy, and a sharp increase in industrial sectors including high temperature heat, power, and for the production of advanced biofuels used in road, marine and aviation transport sectors. Long term climate policies are likely to drive a further increase of solid biomass demand.[25] Considering demand of biomass feedstocks for bioenergy and the bioeconomy, the biomass trade will likely further grow to sourcing countries to mobilise up-tapped biomass potentials.

Given the EU as a global leader of bioenergy use and trade, its well-established policies and clear ambitions towards sustainable future, this thesis focusses on the EU and its policies to develop sustainable bioenergy pathways. Nevertheless, the thesis considers an outlook on sustainable biomass potentials for bioenergy development and bioenergy sustainability at a global level.

1.2. IMPACTS OF BIOENERGY PRODUCTION AND CONSUMPTION

Bioenergy is recognised as a key option to replace fossil fuels, reduce GHG emissions, and contribute to local economic development.[26–30] Next to climate change mitigation, the Sustainable Development Goals (SDGs) also highlight the potential roles of modern bioenergy.[31] Modern bioenergy can contribute to SDG7 on affordable and clean energy through an access to affordable, reliable and modern energy services, for example electricity and clean fuels. In addition, modern bioenergy can contribute to other SDGs, such as SDG12 on sustainable consumption and production through a sustainable management and efficient use of biomass feedstocks.

Economic aspects of bioenergy production can have positive impacts of rural development. Bioenergy projects have demonstrated to create jobs for local communities and contribute to economic growth.[26,32] Social impacts of bioenergy development are mixed.[30,33] Some agricultural lands are marginal for food production, and bioenergy production could improve these marginal lands and provide benefits to biomass producers.[28,34] However, there are also major sustainability concerns associated with bioenergy production and consumption. These concerns include low GHG emission savings due to supply chain emissions and biogenic GHG emissions due to changes in land carbon stocks; negative impacts on agricultural systems; impacts on biodiversity; impacts on water, soil and air quality; feedstock competition; impacts of land use change; and negative social impacts.[31,35]

The supply chain emissions of imported biomass and biofuels from distant sourcing countries might further increase supply chain GHG emissions.[33] An increasing bioenergy demand may possibly lead to a pressure on forests through higher harvest levels or increased imports of biomass, especially wood pellets.[36] Subsidies can increase the purchasing capacity of bioenergy users, and thereby can lead to competition with non-energy markets such as wood panels, and pulp and paper sectors.[30,37] Increase of bioenergy consumption also raises concerns over competition with food and feed production on existing agricultural land.[38,39] The production of agricultural biomass for bioenergy can result in negative impacts on soils (for example loss of nutrients and soil organic matter, erosion, peatland drainage), water availability (in particular in water scarce areas) and biodiversity.[40,41] (Indirect) land use change induced by bioenergy ((i)LUC) may have cause various associated environmental impacts. Environmental impacts of (i)LUC and land use management for biofuel feedstock production vary according to feedstock, soil type, agricultural and conversion technology.

To address these sustainability concerns, sustainability criteria have been developed and implemented in various policies and voluntary certification systems. Sustainability principles have also been included as part of good practices guidelines.[42]

1.3. SUSTAINABIILTY CRITERIA AND VOLUNTARY CERTIFICAITON AS MEANS TO ENSURE BIOENERGY SUSTAINABILITY

The concept of sustainable development and sustainability has been developed since the late 1980s.[43] In 1992, the Earth Summit was organised acting as a platform for interested countries to respond to main global sustainability issues such as systematic scrutiny of production, and alternative energy sources to replace fossil fuels and mitigate climate change. The years after the summit, several sustainability initiatives have been established by interested stakeholder groups who were committed to pursuing sustainable development. In these sustainability initiatives, sustainability principles, standards, and criteria were established to respond to environmental, social, and economic concerns to demonstrate sustainability performance of organisations and products in specific areas.

In the bioenergy sector, sustainability principles were identified in the early 2000s in the EU Member States, for example in Belgium, the Netherlands, and the UK.[44] Some years later, sustainability criteria have been mandatorily implemented in the national laws and regulations in those countries to assure sustainable biomass production and trade.[45] Sustainability criteria are also developed in voluntary schemes that provide voluntary certification of sustainable bioenergy and resources.[46] Sustainability of bioenergy and other related sectors is also promoted through best management practices.[47,48] These strategies to assure the sustainability of bioenergy are explained in more detail in the following sections.

1.3.1 Laws and regulations

Bioenergy is encompassed in the wide bioeconomy that covers food, feed, forest products, waste and residues, and energy,[21] and the sustainability of bioenergy is also partly regulated through a number of national and EU policies within these sectors. In the EU, these policies include the Common Agricultural Policy (CAP), Forest Europe, EU Timber Regulation (EUTR), LULUCF regulation and air quality legislation.[48–50] The CAP aims to assure a sustainable farming by avoiding environmentally harmful agricultural activity, and enhancing the sustainability of rural ecosystems. To ensure sustainable agricultural activities, farmers are obliged to respect common rules and standards for protecting water and soil resources, air quality, and preserving landscape. The common policy framework Forest Europe was established to promote, improve, and implement sustainable forest management (SFM) in the whole EU. The framework, covering common principles, criteria, and indicators, serves as guideline for National Forest Programmes. Biomass from forests must comply with the SFM principles safeguarding not only the economic but also ecological and social functions of forests. The EUTR requires a legal harvesting of timber. It counters the trade in illegally harvested timber and timber productions. The EUTR also requires EU traders who place timber products on the EU market for the first time to exercise due diligence in order to minimise the risks of illegal harvesting.

These aforementioned policies are designed mainly for sustainable land use and feedstock supply for non-energy markets such as food, feed, and fibres. Most of these policies are tailored for the EU bioeconomy sectors, therefore they address certain impacts mainly within the EU. They lack requirements to lifecycle GHG emission savings, or land use outside the EU that became a major concern, in particular liquid biofuels. To this purpose, the EU introduced binding sustainability criteria to liquid biofuels used in transport and bioliquids used in electricity, heating and cooling in the RED I in 2009. Proof of compliance to these sustainability criteria can be demonstrated either through national legislation or through voluntary certification schemes that are recognized by the EC.

Although sustainability criteria for solid biomass were not legally binding at the EU level, several EU Member States that import solid biomass for bioenergy have implemented sustainability criteria to address sustainability concerns. These countries include Belgium, the Netherlands, and the United Kingdom (UK), the main importing countries of wood pellets for industrial use. These criteria are mandatory under national legislation in the aforementioned countries. Similar sustainability criteria are also voluntarily implemented under the industrial initiative-initiated voluntary framework in Denmark.[51] Under these systems, economic operators can submit sustainability evidence to the national authorities, or use sustainability certificates of the voluntary schemes recognised by national authorities to demonstrate sustainability compliance against the sustainability criteria.

In 2018, the revised Renewable Energy Directive (RED II) was adopted.[52] Amongst others, it establishes a new set of sustainability criteria for the whole bioenergy sector aiming to minimise environmental impacts, deliver GHG emissions reductions, promote resource efficiency, and avoid market distortions. The sustainability criteria in the RED II are currently being transposed into national legislations which will be implemented from 2021 onwards.

Outside the EU, relevant legislations for bioenergy are also established in many other countries. Some prominent examples are Canada, the US, and Japan. In Canada, the Canadian Environmental Protection Act established the Renewable Fuels Regulations (RFR) in 1999, which came into force in 2010. The RFR was formed with the aim to reduce GHG emissions by requiring an average 5% renewable fuel content in gasoline, and 2% renewable fuel content in diesel fuel and heating distillate oil, for each compliance period.

In the US, the Congress established the Renewable Fuel Standard (RFS) program to reduce GHG emissions and expand the renewable fuels sector, while reducing reliance on imported oil.[53] This program was authorised under the Energy Policy Act of 2005 and expanded under the Energy Independence and Security Act of 2007. The RFS sustainability requirements include restrictions on GHG emissions of renewable fuels in which the thresholds are minimum 20% reduction for conventional biofuels, minimum 50% reduction for advanced biofuels, and 60% reduction for cellulosic biofuels. The RFS sustainability requirements also include restriction of feedstock types and the types of land that can be used to grow and harvest the feedstocks. Land put into cultivation after December 13, 2007 is excluded. Tree crops, tree residues, and biomass grown on federal land are also excluded as permissible feedstocks.

In Japan, the current renewable energy policy focuses on the generation of power from solar, wind, biomass, and geothermal sources. Woody biomass fed in power plants has been increased since the introduction of a feed-in tariff (FiT) scheme in 2012.[18] Low-cost biogenic fraction of waste and forest residues are used as main feedstocks. In the Sophisticated Methods of Energy Supply Structure Act of 2010, the Japanese government established an environmental sustainability standard for biofuels to ensure no land competition with food supply. Biofuels must also reduce GHG emissions by at least 50% when compared to fossil fuel emissions based on a life cycle assessment (LCA).

1.3.2 Voluntary certification systems

With the implementation of the RED I, sustainability certification has become a prerequisite for economic operators to receive financial supports of using liquid biofuels. Using voluntary schemes that are recognised by the EC is an approach to verify that biofuels and bioliquids are sustainably produced. Under such a sustainability surveillance, sustainability certification is considered a proof for biofuel suppliers to comply with sustainability criteria, as well as possibly gain social acceptance and market confidence to penetrate into the EU and global bioenergy markets. Voluntary certification schemes are the most commonly used tool to demonstrate compliance with the EU sustainability criteria. However, coverage of sustainability criteria and reporting requirements in voluntary schemes might be different with the criteria coverage in national legislations. Sustainability criteria established in national legislations reflect national focuses and ambition to promote particular types of renewable energy. Sustainability criteria defined in voluntary schemes address sustainability aspects of various sectors and might go beyond the national and EU sustainability framework.

So far, the International Sustainability & Carbon Certification (ISCC) has been the most widely used voluntary scheme for biofuel certification in the EU.[11,54] For example, in the Dutch biofuel market, ISCC has increased its share from about 55% in 2011 to nearly 100% of total certified biofuels in 2018.[55]

In the countries which implement sustainability criteria for solid biomass, voluntary schemes including Forest Stewardship Council (FSC), Programme for the Endorsement of Forest Certification (PEFC), and Sustainable Biomass Programme (SBP) are widely used. The FSC and PEFC are two of the first voluntary schemes established in the mid 1990s aiming to improve forestry practices worldwide and certify sustainable forest. By the end of 2018, SBP-certified pellets account for 65% of the EU's industrial pellet consumption and SBP has been found to be the most widely used voluntary scheme for solid biomass certification.[56] Certified biofuels and wood pellets are presented in Figure 1.1.

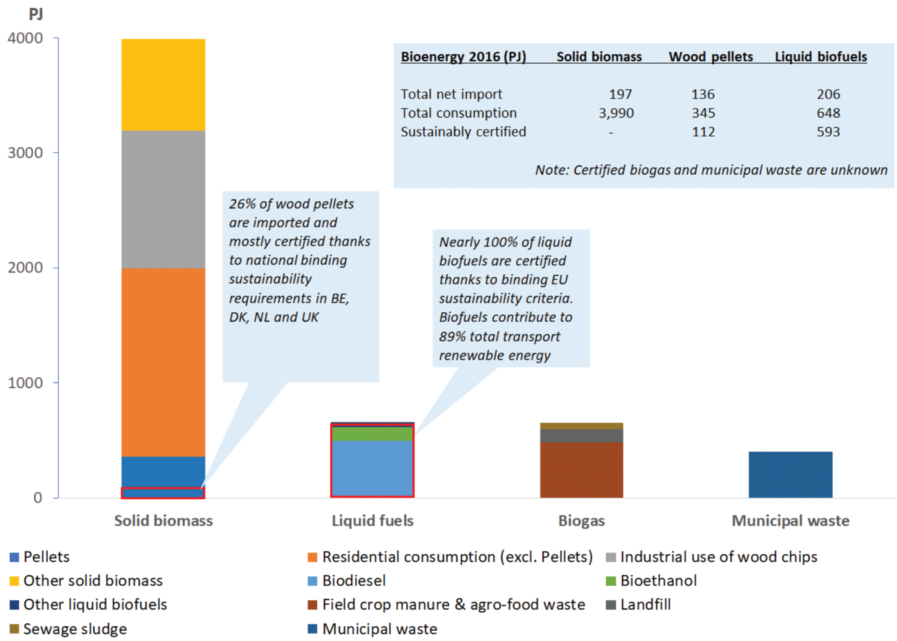


Figure 1.1. Total final bioenergy consumption in the EU in 2016, differentiated between liquid biofuels, solid biomass, biogas and the organic fraction of municipal waste in 2016. For solid biomass and liquid biofuels, the certified share of biofuels and solid biomass is estimated based on [23,57,58]

In other regions outside the EU, sustainability compliance for feedstocks used for bioenergy production can also be demonstrated through a voluntary approach. Canada and the US export wood pellets to the EU for bioenergy production; therefore, they need to meet the existing sustainability criteria for solid biomass in some Member States as well as to meet the EU wide sustainability criteria for the whole bioenergy sector starting as of 2021. So far, certified wood pellets exported from the US and Canada to the EU are provided by certain voluntary schemes such as FSC, Fibre Sourcing Standard (SFI Fibre Sourcing), SBP and PEFC.[51]

In Asia, Japan accepts certification of voluntary schemes such as FSC and the Roundtable on Sustainable Palm Oil (RSPO) to demonstrate sustainability compliance of woody biomass and agricultural residues.[18] However, these schemes do not take into account any requirements for GHG emissions reduction. The Japanese government is likely to consider the establishment of binding sustainability criteria including a requirement for GHG emissions reduction in combined heating and power plant (CHP) using biomass.[18] The Republic of Korea might also consider an implementation of sustainability criteria as they also establish policies stimulating the import of biomass for bioenergy production.[59] However it is not yet known how and when such an implementation may happen.

1.3.3 Promotion of good management practices

In the EU, increased use of forest biomass for bioenergy has to be ecologically sustainable and good forest management practices are promoted. EU-wide reporting, which considers qualitative indicators for SFM defined in Forest Europe, is implemented providing good practices towards achieving the global forest goals, global climate change agreement and ultimately presenting sustainable forest biomass used for bioenergy production. Forest management is also regulated on a member state level (except for the EUTR), and thus can be any mix of voluntary and mandatory measures.[60] In the EU CAP, farmers receiving direct payments need to comply with the agricultural and environmental standards set out under the cross-compliance system, and carry out specific agri-environmental practices favourable to the environment.[47,61]

In the US, sustainability criteria for forest biomass are considered in good management practices. The Code Titled Conservation covers a wide range of laws governing how the Forest Service and other agencies manage public lands of which forest biomass is harvested. The laws among others, define national forests, restoration management, protection of timber, forests, forest and renewable resources planning. All states have developed Best Management Practices (BMPs) to ensure protection of water quality, proper timber harvesting, and proper forest management operations. Sixty four sustainability indicators are included in BMPs establishing a quantitative baseline for measuring progress toward sustainability.[62]

1.4. KNOWLEDGE GAPS

1.4.1 Concerns of bioenergy development, and position and vision of stakeholders towards bioenergy

The concerns and viewpoints of stakeholders towards bioenergy are important to establish strategies towards sustainable development of the bioenergy sector. In the past decades, the contributions of bioenergy to mitigate climate change and secure energy supply have been informed to external stakeholders; therefore, the roles of bioenergy are acknowledged by certain stakeholder groups.[63,64] Some stakeholder groups recognise positive roles of bioenergy in job creation, local economy development, reinforcement of energy security by producing biofuels from local feedstocks.[63–65] However, the current and future role of bioenergy in sustainable energy supply has become disputed among stakeholders due to potential negative impacts of bioenergy linked to inefficient and unsustainable biomass consumption.[66] Some stakeholder groups are sceptical about benefits of bioenergy due to a variety of arguments such as unsustainable cultivation, feedstocks harvesting, and land use change impacts.[64,65] Until recently, studies which have investigated the perception and position of stakeholders towards bioenergy mainly focused on specific bioenergy supply chains in specific regions, for example the EU, the United States, and Asia.[67,68] Or the focus was on specific aspects such as bioenergy governance, and social acceptance of bioenergy.[64,69] These studies have addressed a number of isolated issues such as feedstock preferences for bioenergy; multi-level governance and impacts of governance on bioenergy production and trade; awareness about bioenergy; and attributes driving opinions about bioenergy. These studies were mainly carried out through online surveys with general questions on perception and position of stakeholders. Other methods such as interviews and roundtable discussions which require more comprehensive answers, opinions and vision were rarely included.[65] Stakeholders groups that participated in these studies were also limited in terms of group classification. Based on a review of studies by Radics et al.,[65] the stakeholder groups were mostly represented by general public, consumers or consultancies.

There is a lack of comprehensive consultation through a combination of communication channels including online surveys, roundtable dialogues, and interviews to investigate the position and vision of stakeholders towards bioenergy at a global level. There is also often lack of investigation of key aspects, which are important to reveal the position and vision of stakeholders. These aspects include awareness of bioenergy development, bioenergy value chains and related sustainability impacts, conditions to support and disapproval of bioenergy. Results of such an extensive consultation can explain how bioenergy is viewed and accepted by stakeholder groups at a global level, and will ultimately help the bioenergy sector to develop further in a sustainable pathway.

1.4.2 Sustainable biomass potentials for bioenergy production

The growth of modern bioenergy in large economies such as the EU, Japan, and Republic of Korea, has led to an increase of biomass import to these regions, and international biomass trade will likely continue growing in the future.[70–72] Within the EU, domestic supply potentials of biomass can potentially meet the demand for energy and other purposes up to 2050.[73] However, due to economic and other barriers including high feedstock costs, geographical spread and variation in biomass quality, the need for international biomass trade between regions of abundant biomass and low-cost supply with regions of high demand will likely grow in the future.[23] Given the sustainability concerns of bioenergy development, a consistent assessment of sustainable biomass potentials is needed for the existing and emerging export regions which are competitive and meet the EU sustainability criteria for bioenergy.[52] This could also help the identification of unused or underutilised sustainable feedstocks in sourcing regions.

Lignocellulosic biomass feedstocks are the most abundant biogenic resources on earth. They are the non-edible parts of plants and therefore are not likely to compete directly with food and feed supplies.[74,75] Lignocellulosic biomass feedstocks are promising alternatives to limit fossil fuel use.[74] Disposal of these wastes by landfilling them or burning of residues in the field may cause environmental problems; however, they can be utilised for the production of a number of value-added products. Lignocellulosic biomass can also be produced with no or very limited amounts of fertilizers and herbicides, and mobilised at higher yields; therefore, they have in general more advantages than many food-based bioenergy crops.[75] Thus, lignocellulosic feedstocks are considered promising for the production of bio-based products as well as biofuels, heat and electricity.

A number of studies have developed methodologies to estimate lignocellulosic biomass potentials.[76–79] These studies or used a spatial modelling to assess potentials which require considerable efforts, or considered statistical approach assuming various factors such as yields, or land suitability to estimate potentials. Nevertheless, there is a lack of comprehensive studies to estimate feedstock potentials including residues in multiple sourcing regions that include a practical approach and (on an aggregate national level). Rarely, studies took into account sustainability criteria and GHG emission reduction along the supply chains, which are applicable in practice (in the studied countries). There is also a lack of studies which comprehensively consider local barriers, priority for local uses of biomass ahead of exports, pre-treatment capacity and mobilisation opportunity to estimate potentials.

1.4.3 Effective sustainability criteria and harmonisation of sustainability requirements

Binding sustainability criteria are currently required for biofuels and bioliquids at the EU level. Next to national legislation, a variety of voluntary schemes are recognised by the EU to be used to demonstrate sustainability compliance with these criteria. Some voluntary schemes also define additional sustainability criteria and requirements that are tailored to specific scopes and end-uses. Differences in level of strictness and inclusion of sustainability criteria in voluntary schemes are challenging for stakeholders to make a selection of relevant voluntary schemes to certify sustainable biofuels and bioliquids at the national level. Some voluntary schemes are designed to demonstrate compliance with legal requirements, while other voluntary schemes aim to go beyond legal requirements with additional and stricter sustainability criteria to address wider sustainability concerns.[81,82] The more comprehensive schemes include, for example RSB. However, there is a trade-off between the inclusion of a broad and stringent set of sustainability criteria and the associated cost and administrative burdens that could become a barrier for implementation.

Although not binding at the EU level, sustainability criteria for solid biomass have been established in some EU Member States, mainly those that import solid biomass for industrial purpose (heat and electricity generation). National legislation in one country may have different requirements and therefore consist of different sustainability criteria compared to the requirements in other national legislations and industrial initiatives in other EU countries. Divergence between national sustainability criteria can lead to international and intra-EU trade barriers and may cause a risk to the internal market within the EU for solid biomass. The divergence may also lead to additional administrative costs in complying with various sustainability requirements, and will ultimately make it more difficult and costly to meet the increasing biomass demand.[82] Previous analyses on the development of sustainability criteria for solid biofuels already identified these barriers and indicated the need for harmonisation among certification systems.[83,84] Figure 1.1 provides an overview of certified bioenergy in 2016, reflecting the implementation of EU binding sustainability criteria for biofuels and national sustainability criteria for solid biomass. Whilst certified biomass and biofuels are reported, certified biogas is not reported and thus cannot be estimated.

There is a lack of assessments on harmonisation possibilities of national sustainability requirements for solid biomass given the possible trade barriers and challenging situation for stakeholders involved in the biomass supply chains to provide sustainability reporting. An investigation of harmonisation possibilities would assist economic operators in demonstrating sustainability compliance, and provide suggestions for policymakers for the improvement and alignment of national sustainability requirements.

Also at EU level, binding sustainability criteria for the whole bioenergy sector are established in the RED II and will be implemented in the EU by 2021 onwards. However, the RED II defines only certain environmental criteria, and in the meantime allows Member States to establish additional sustainability criteria for solid biomass used in electricity, heating and cooling. The RED II does not establish social and economic criteria, and there might be sustainability risks particularly in sourcing regions where export biomass feedstocks and bioenergy to the EU.[85,86]

The limited sustainability criteria established in the RED II might bear some sustainability concerns which have been identified in several position papers.[87–89] Those concerns include unclear definitions of certain sustainability criteria, risk of unsustainable mobilisation of feedstocks, and iLUC risks. However, there is a lack of studies accomplishing comprehensive assessment on how these criteria will be implemented in practice. With new and updated sustainability criteria, policy makers probably face challenges to establish sustainability criteria for various types of bioenergy, to benchmark and recognise competent voluntary schemes to demonstrate sustainability compliance at national level. Various sustainability criteria have been implemented separately in many voluntary schemes and national legislations. Thus, there might be lessons which have not discussed that stakeholders can learn from establishment and verification of sustainability criteria in those systems for the promotion of sustainable bioenergy in Member States. Voluntary scheme owners, certification bodies and auditors equally need clear guidance to measure sustainability criteria and certify sustainability of bioenergy. A study of possible sustainability concerns in the RED II and an identification of effective sustainability criteria for bioenergy will help involved stakeholders to implement and assure sustainability compliance of bioenergy.

1.5 THESIS OBJECTIVES AND RESEARCH QUESTIONS

This thesis focuses on lignocellulosic feedstocks for the production of bioenergy. The main objective of this thesis is to investigate the required conditions for the bioenergy sector to move towards more sustainable pathways. To this purpose, the following research questions will be addressed:

I. *What are main concerns raised by stakeholders regarding environmental, socio-economic impacts of bioenergy, and what are their position and vision towards sustainable bioenergy?*
II. *How are sustainable biomass potentials determined in various sourcing regions? What are the resulting sustainable export potentials?*
III. *What are effective sustainability criteria for bioenergy, taking into wider sustainability concerns and practical implementation issues?*

These questions are addressed in Chapters 2-5 of this thesis (Table 1.1) within a confined geographical and temporal scope. The geographical scope of this thesis is mainly set for the EU, but the thesis also considers global biomass potentials to be possibly imported to the EU from international sourcing regions. The temporal scope of this thesis is focus on the short (2020) and medium term (2030) to assess policies and sectoral development for bioenergy more precisely.

Table 1.1 Overview of the thesis chapters and their relation to the research questions

Chapters		Research questions		
		I	II	III
2	*Towards a harmonisation of national sustainability requirements and criteria for solid biomass*			x
3	*Charting global position and vision of stakeholders towards sustainable bioenergy*	x		x
4	*Sourcing overseas biomass for EU ambitions: assessing net sustainable export potential from various sourcing countries*		x	
5	*Effective sustainability criteria and certification for bioenergy sector at EU level: Towards the implementation of the Renewable Energy Directive II*	x		x

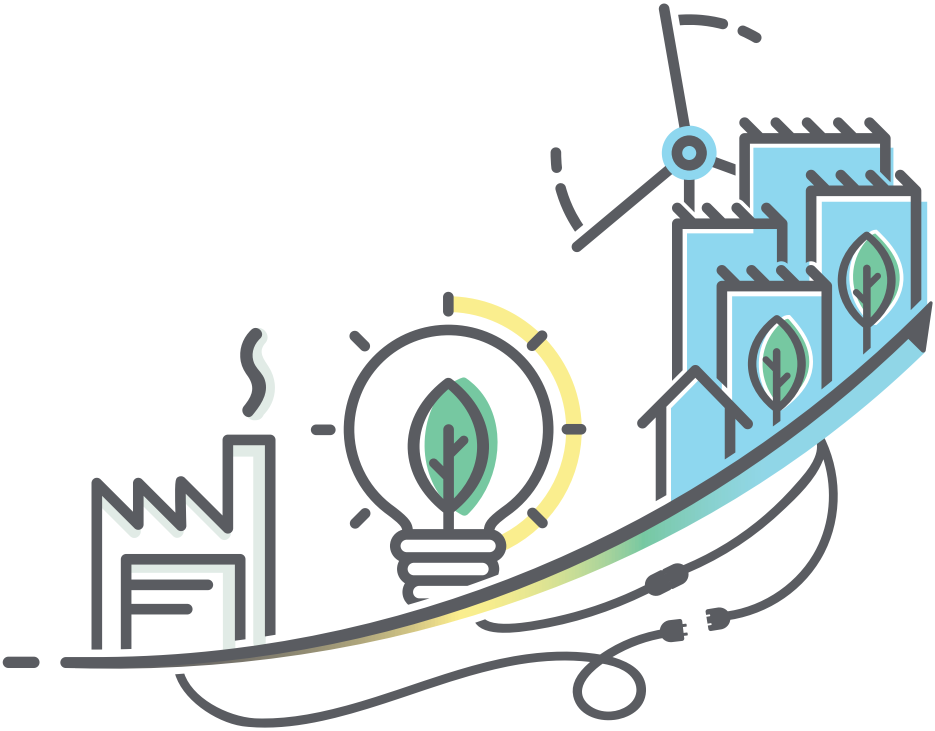
Chapter 2 provides an overview of sustainability requirements for solid biomass defined in national legislations in Belgium, the Netherlands and the UK, as well as in an industry

agreement in Denmark. These are the four countries that import solid biomass for heat and power generation. Given the adoption of the Renewable Energy Directive (RED I) and the absence of mandatory EU wide sustainability criteria for solid biomass, these countries have established sustainability criteria for solid biomass. However, different systems and sustainability criteria may present barriers to trade and sustainability certification. This chapter assesses some possibilities for harmonisation of sustainability criteria among EU Member States, and provides suggestions for policymakers for the improvement and alignment of national sustainability criteria.

Chapter 3 examines position and vision of a wide range of stakeholder groups, including supranational stakeholders, towards bioenergy and its development at a global level. The examination includes an identification of stakeholders as belonging to one of seven stakeholder groups and the role of each group in relation to bioenergy. A consultation of an online survey, roundtable dialogues and interviews with the stakeholder groups reveals their stated awareness and opinions of bioenergy development, feedstocks used for bioenergy productions, and existing barriers and challenges. An data analysis is carried out to compare interests and influence as a basis for expressing position and vision, as well as provide recommendations for gaining or enhancing support for sustainable bioenergy development.

Chapter 4 assesses sustainable biomass export potentials from selected countries by applying a number of local factors and sustainability criteria relevant for these specific countries. This demonstrates a test of sustainability compliance for Brazil, Colombia, Indonesia, Kenya, Ukraine, and the US. Only biomass types with the highest potentials are selected, to take advantage of economies of scale, for example pulpwood, wood waste, and residues in the United States, and agricultural residues in Ukraine. This chapter also investigates biomass markets in the sourcing regions and identifies influence of pellet mill capacity and the pellet industry to bioenergy trade. Factors of demand, market price, sustainability criteria, GHG emissions and distance among sourcing and import regions are taken into account to assess net sustainable biomass export potentials.

Chapter 5 reviews sustainability criteria for bioenergy established in RED II, voluntary schemes, and in national legislations. A certain number of sustainability criteria are defined in the RED II, whilst more comprehensive and strict sustainability criteria for bioenergy exist. The RED II determines binding sustainability criteria for biofuels but allows Member States to add stricter sustainability criteria for heat and electricity. It is unclear how the RED II should be translated into national legislation to assure sustainability compliance. The chapter therefore investigates sustainability concerns, and relevant sustainability criteria implemented in practice and considered in scientific studies to provide effective sustainability criteria for various types of bioenergy. An assessment is accomplished to investigate sustainability criteria implemented in national legislations and voluntary schemes to reveal to what extents they are more (or less) comprehensive than the RED II to demonstrate sustainability compliance. Based on the review and assessment, the chapter provides recommendations to policy makers, sustainability practitioners and relevant stakeholders in establishment and implementation of sustainability criteria for bioenergy in the period after 2020s. The chapter also provides practical information for the involved parties regarding certification and verification of sustainable bioenergy to ultimately assure sustainability compliance.



2

Towards a harmonisation of national sustainability requirements and criteria for solid biomass

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2.1 INTRODUCTION

Renewable energy plays an important role in the European energy sector as it reduces the dependence of the European Union (EU) on fossil fuels and mitigates climate change.[90] In 2009, the European Commission (EC) issued the Renewable Energy Directive (RED I)[91] in which Member States (MS) set targets to the share of energy from renewable sources in gross final energy consumption by 2020. To ensure the sustainability of liquid biofuels (one type of bioenergy) used in the transport sector, the RED I established sustainability criteria irrespective of whether the feedstocks are cultivated inside or outside the EU territory. Solid biomass, largely sourced from processing and harvesting residues, is also used to produce bioenergy (mainly for electricity, heating and cooling) and is considered as a potential source of renewable energy as well as a way to achieve greenhouse gas emission (GHG) reduction[a]. Solid biomass is the biggest source of renewable energy in the EU and is expected to make a key contribution to the 20% EU renewable energy target by 2020.[92] The RED I has no binding sustainability requirements for solid biomass at the EU level, probably due to the challenges of establishing a harmonised scheme for a wide variety of biomass as well as the low sustainability risks relating to domestic biomass production.[91] However, the EC proposal issued in November 2016 on the promotion of energy from renewable sources reinforces the existing EU sustainability criteria for bioenergy by extending the scope to cover both biomass and biogas for heating, cooling and electricity production.[93]

Regarding biomass sustainability, there are concerns expressed by some non-governmental organisations on the sustainability risks of production, and to a lesser extent, transport and use of solid biomass, which are not cover under the current sustainability criteria of the RED I.[94,95] Possible risks include reduction in carbon stocks when removals exceed annual productions in forests; energy generated using biomass may not lead to substantial GHG emission savings compared to fossil fuels; competition between energy and material use (among pulp & paper, energy and construction industries); unsustainable forest management and negative impacts on biodiversity and quality of land. Other issues such as indirect land use change (iLUC), impacts on water resources and the environment, land right conflicts, and non-compliance social regulations have also been identified.

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a *The most common applications of biomass for heat and power production reduce greenhouse gas emissions by 55 – 98% compared to the fossil fuel mix* [111]

In Europe, forest biomass for energy is largely a complementary co-product of wood material/ fibre products, and therefore it is unlikely that bioenergy demand is associated with direct deforestation on a large scale in Europe.[92] Certain non-governmental organisations (NGO) have however claimed unsustainable sourcing practices of woody biomass for a number of specific cases in the EU.[95] Although the volumes of solid biomass used for energy production are relatively small compared to overall solid biomass use, the volume of solid biomass imported from outside the EU for energy use has been increasing in recent years,[96] and the sustainability of this sourcing has been questioned, especially from the US South to the EU.[95]

The main importing countries for solid biomass in the EU are the UK, Belgium, the Netherlands and Denmark, also these are the focus countries of this paper. There is increasing pressure from various stakeholders for the implementation of sustainability requirements covering sustainable production and use of solid biomass for large scale heat and energy generation. In the absence of sustainability criteria for solid biomass being set at a European level, the EC has encouraged its Member States to develop their own sustainability criteria for solid biomass based on the EC recommendations on addressing land use, land use change and forestry as well as GHG emissions performance.[92] As a consequence, a number of industrial bioenergy users (e.g. RWE, Engie, Drax Power, Dong Energy) have voluntarily developed their own sustainability criteria for sourcing biomass. Also a number of European countries have already implemented support and voluntary schemes to govern the sustainable production and use of solid biomass. Belgium has implemented three Green Certificate schemes (GCs) for solid biomass used for electricity generation that include sustainability principles since 2002. The system(s) are expected to be revised shortly and to become more comprehensive. The UK has implemented binding sustainability criteria for sustainable biomass used for the production of heat and power since 2016. Denmark has also implemented a voluntary scheme to support the sustainable use of solid biomass for energy production in 2016. In the Netherlands, sustainability criteria have also been developed for solid biomass used for co-firing and large-scale heat production. Details are still being finalised, such as the means of verification and eligibility of existing sustainable forest management (SFM) systems.

2.2 THE NEED FOR ASSESSMENT OF NATIONAL SUSTAINABILITY REQUIREMENTS FOR SOLID BIOMASS

Review of the national support and voluntary schemes showed that each of the focus countries has its own sustainability requirements. Differences between national sustainability requirements cause trade barriers for solid biomass, and also represent an administrative cost in demonstrating compliance. Previous analyses on the development of sustainability criteria for solid biofuels recommended harmonization of certification systems for sustainable biofuels.[82,97] This paper emphasises the importance of reviewing sustainability criteria in the focus countries to understand the requirements in demonstrating sustainability compliance of solid biomass used for bioenergy. The paper additionally aims to provide solutions that help facilitate sustainable biomass trade for suppliers and generators of solid biomass, as well as recommendations for policy makers setting sustainability requirements.

In detail, this paper focuses on:

- Assessing and comparing the current proposed sustainability requirements in the focus countries
- Identifying differences and evaluating the comprehensiveness of sustainability criteria and reporting requirements
- Investigating differences between national criteria linked to sustainable forest management with voluntary certification systems and verifying which systems are recognised in the national support schemes
- Providing recommendations for improvement and possible alignment of criteria towards a system of harmonised sustainability criteria and reporting requirements.

In this paper, the support schemes and their associated sustainability requirements in the focus countries are firstly introduced, and the methodology used to review these schemes is described. The process of consultation with stakeholders regarding policy development, scheme updates and opinions regarding the level and inclusion of various sustainability requirements are presented. Results of the study are shown in the next part. Finally, conclusions are presented and recommendations are made for further improvements to national sustainability requirements.

Sustainability criteria and sustainability requirements

To clarify the study focus and also to align different sustainability issues identified in the national support and voluntary schemes, the terms sustainability requirement and criteria are defined. They will be used intertwined. More explanation is provided in Supplementary Information (S.I.) 2.1.

Differences of voluntary certification systems and national schemes

A number of voluntary certification schemes are recognised and used in the four investigated countries to demonstrate compliance with national sustainability requirements. Each voluntary certification scheme has a specific scope for what it certifies. For example, the scope of current certification schemes may cover the legal and sustainable sourcing of forest biomass but not GHG footprint calculations.

2.3 NATIONAL SUPPORT SCHEMES FOR SOLID BIOMASS USED FOR BIOENERGY PRODUTION

2.3.1 UK legislation on sustainability of solid biomass for bioenergy production

The UK aims to produce 15% of its energy from renewable sources in gross final consumption of energy by 2020 and biomass is expected to make a significant contribution to delivering renewable energy target of the UK.[98] The UK government has established sustainability requirements for biomass feedstocks in relation to the sustainable sourcing and production of biomass. The Department for Business, Energy and Industrial Strategy (BEIS) and the Department of Transport introduced four support mechanisms: the Renewables Obligation (RO)[b], the Renewable Heat Incentive (RHI)[c], the Contracts for Difference (CfD)[d] and the Renewable Transport Fuel Obligation (RTFO)[e]. Each of these includes sustainability requirements for solid biomass. Among these initiatives, the RO is the UK government's main support mechanism to incentivise deployment of large-scale renewable electricity generation.[98] The RO mechanism has been further investigated in this paper as it contains all the relevant sustainability requirements set out in UK legislation.

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b *RO is the main support mechanism for large-scale renewable electricity projects in the UK*

c *RHI includes Domestic RHI for homeowners, private landlords, social landlords and self-builders as well as Non-domestic RHI to provide payments to industry, businesses and public sector organisations*

d *CfD is the long-term contracts to encourage investment in new, low carbon generation*

e *RTFO is the mechanism to support the UK government's policy on reducing greenhouse gas emissions from vehicles by encouraging the production of biofuels that don't damage the environment.*

The aims of the sustainability requirements for solid biomass under the RO are to deliver real GHG emission savings whilst assuring that solid biomass is produced in a way that does not give rise to deforestation or degradation of habitats or loss of biodiversity. It also aims to guarantee that solid biomass is cost effective as well as its production and use does not give rise to unintended consequences.[98]

2.3.2 Belgian mechanisms to promote renewable bioenergy from solid biomass

Belgium sets a target to achieve 13% of renewable energy in the final energy consumption until 2020.[91] In 2002, the Green Certificate mechanisms were introduced.[99] The mechanisms promote the usage of renewable sources for electricity production through a quota system based on obligations, tradable certificates and minimum prices, as well as promote the sustainable certification and subsidies for the investment and utilisation of renewable electricity. The trade of certificates is subject to federal legislation, while the quota obligations are defined in regional regulations. Electricity suppliers need to show evidence that they have supplied a certain quota of renewable energy determined by three regions Flanders, Wallonia, and Brussels-Capital (which have almost the same requirements so that they are integrated as one region for further investigation) to their final consumers.

The quota systems do not include sustainability requirements for various types of renewable energy. But the systems require SFM evidence for forest biomass: certified or at least evidence such as type of raw materials, energy and CO_2 balance of the supply chain to an accredited inspection a proof of compliance with responsible management of the forests, controlled impact on environment and enforcement of legislation.[100] In Flanders, additional requirements relating to the cascading use of biomass have been established.

2.3.3 Danish Industry Agreement

Denmark has a relatively high share of renewable energy and aims to achieve 30% in gross final energy consumption by 2030.[101] Biomass currently presents the largest share of the total renewable energy supply, equalling 65%, including mostly wood, biodegradable waste and straw.[102]

There are no mandatory sustainability requirements for solid biomass used in the Danish energy sector but a voluntary Industry Agreement[f] (IA) was established by the Danish District Heating Association and the Danish Energy Association in 2014. Stated in the agreement, the IA aims to support the use of solid biomass (chips and wood pellets) for energy production in Denmark. The IA attempts to comply with the Danish framework for sustainability regarding environment, health and safety, and climate. The combined heat and power producers are themselves responsible, the producers document and satisfy requirements for sustainability through a third-party. The requirements for sustainable biomass were developed based on the most comprehensive biomass sustainability legislation that existed at the time, namely the UK Sustainability Criteria For Solid Biomass.[103]

2.3.4 Dutch Agreement on Energy for Sustainable Growth

Jointly with Belgium, the Netherlands was one of the first countries in the EU that called for sustainability requirements for solid biomass at national level. The Cramer Commission specified comprehensive sustainability categories defined in a governmental project for sustainable production of biomass including criteria for GHG emissions and carbon stocks, competition for food production and local applications of biomass, biodiversity, environmental impacts on water, air and soil, as well as social well-being. Since then, more voluntary certification schemes had been developed such as the Better Biomass, which are based on Cramer criteria.[104]

In 2009, the Commission for Biomass Sustainability was established with the aim of advising the Dutch government on a number of issues related to biomass sustainability including sustainability requirements for solid biomass. In 2013, the Netherlands Enterprise Agency (RVO) published the 'Energy Accord for Sustainable Growth' stating that biomass used for co-firing and heat production must meet a number of sustainability criteria. As part of the Dutch 2013 Energy Accord, the Sustainable Energy Production Incentive Scheme (SDE+) has been introduced including sustainability criteria set in legislation based on Better Biomass requirements, and additionally covering carbon debt, iLUC and SFM requirements.

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f *The agreement is binding for industry to demonstrate sustainability compliance of biomass use for bioenergy*

2.4 METHODOLOGY TO COMPARE SUSTAINABILITY REQUIREMENTS AND EVALUATE THE COMPREHENSIVENESS OF NATIONAL SUPPORT SCHEMES

A four-step methodology was established to compare the sustainability requirements and evaluate the comprehensiveness of the national support schemes (see Figure 2.1).

The first step was analysis of the sustainability approaches that have been developed and applied as well as of the requirements for operators to demonstrate sustainability compliance to authorities. An initial review found that the UK has developed comprehensive criteria and these criteria were adopted as the baseline for the comparison of the national sustainability requirements. Although the evaluation was based on the UK requirements, it was also expanded to include additional requirements and criteria that are not included in the UK system such as cascading and carbon debt criteria. Primary data on the sustainability requirements and criteria in each country were obtained from official national documentation.

The sustainability requirements investigated were GHG emission reduction, land use criteria, carbon debt, iLUC, cascading use of biomass, local land right, chain of custody, and mass balance systems (clarification of these criteria is provided in S.I.2.2). For each requirement, the current level of compatibility was assessed and the possibilities for further harmonisation were briefly discussed.

The second step was to study a number of voluntary SFM certification systems. National schemes also recognise a number of SFM certification systems as a way of assuring that biomass meets part or all of the national sustainability criteria and requirements. This study therefore reviewed relevant SFM schemes to determine how they meet national sustainability requirements and how they might potentially be recognised in the national schemes.

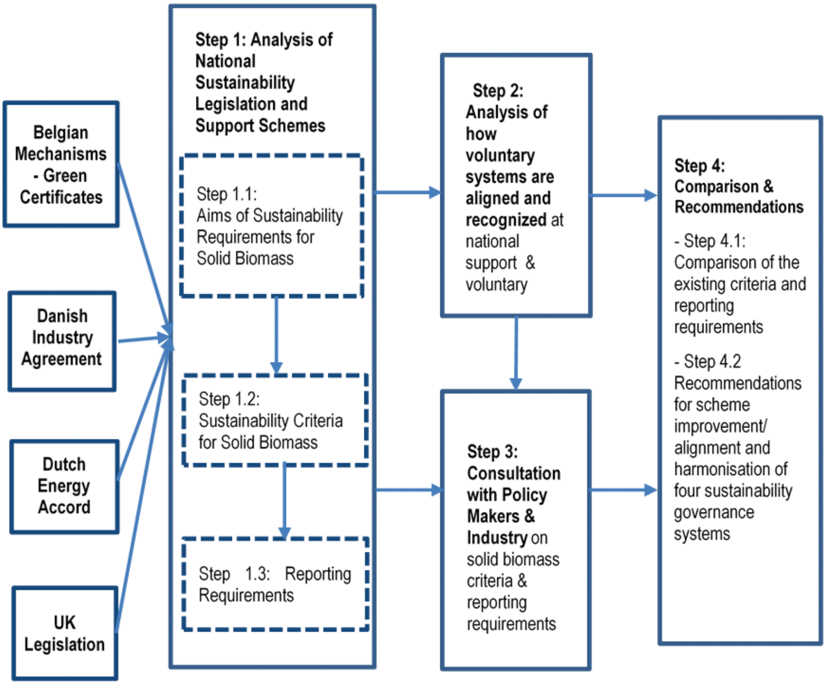

Figure 2.1. Step-wise for comparison and possible harmonisation of national sustainability support & voluntary schemes

The third step consisted of the consultation and discussion with various stakeholders about the comprehensiveness of sustainability criteria, verification and certification processes of sustainable solid biomass, as well as the implementation timeline of the support schemes in the focus countries. Consultation also helped inform understanding of stakeholders opinions on how national support and voluntary schemes are established. Questionnaires were sent to a number of relevant stakeholders and additional information was obtained by two international workshops in which primary policy makers and industry representatives from each of the focus countries participated.

The final step was to review the outputs of the previous steps and compare the sustainability criteria and reporting requirements of these schemes. Recommendations for possible improvement and the harmonisation of sustainability certification systems, also based on the stakeholder consultations, in the four countries were formulated.

2

2.5 RESULTS AND DISCUSSION

2.5.1 Consultation with stakeholders on national schemes and the sustainability requirements

The stakeholders presented at the two workshops (in 2014 and 2015) and individual interviewees provided valuable input and feedback on the conclusions and recommendations of this article. In this section, first the main findings and conclusions from the workshops are summarised (a longer version is included in S.I.2.3) before own conclusions and recommendations are presented.

In general, the consulted stakeholders recognised the importance of establishment and implementation of sustainability requirements on the short term at a national level. Utilities and consultants from both the EU and exporting countries also indicated that significant time and resources are needed to demonstrate both different calculations methods for GHG emissions as well as compliance with other sustainability requirements. Industry representatives also indicated that data collection and sustainability demonstration at the forest unit level is also complicated and challenging to carry out. Therefore, sustainability requirements in various schemes that are interchangeable/ mutually recognised/ harmonised should be considered.

Consulted stakeholders, in particular policy makers agreed that sound scientific methods to determine carbon debt and carbon stocks (including definition, measurement, and management) should be further developed. Representatives from the exporting countries stated that EU policy may have influence on the sustainability certification and biomass market in the sourcing regions. Most of the stakeholders suggested benchmarking sustainability criteria in diverse voluntary certification systems used by biomass suppliers and generators could help them easily demonstrate sustainability compliance to national sustainability requirements. All stakeholders agreed that sustainability criteria set at EU level should be considered to be implemented in the near future.

2.5.2 Comparison of national approach and sustainability requirements

a. Aims of national legislation, support and voluntary schemes for sustainable biomass

The overarching aims of the national support and voluntary schemes in the four countries have both similarities but also significant differences. The Belgian mechanisms mainly seek to optimise the GHG emission reduction, while the UK mechanisms address a wider range of sustainability requirements as well as cost-effectiveness of bioenergy. Although the Danish Industry Agreement and the Dutch Energy Accord have not stated specific aims, their ambitions toward sustainable biomass use are also defined indirectly through the establishment of a comprehensive set of sustainability requirements.

b. Scopes of biomass feedstocks and bioenergy application

The scope and comprehensiveness of sustainability requirements in the four countries are relatively different. Regarding the scope of feedstock use, forest biomass feedstocks are included in all national schemes, and in Denmark agricultural feedstocks are not included. Regarding the bioenergy application scope, three countries use solid biomass for electricity and heat production, namely Denmark (combined heat and power), the Netherlands (co-firing in existing coal power plants and large scale heat producers), and the UK (heat, power plants and co-firing in existing coal power plants) whilst in Belgium the scope is only for electricity production. A summary of feedstock inclusion and bioenergy application scope in national schemes is shown (see Table 2.1).

Table 2.1. Overview of the feedstocks and bioenergy application scopes

Country	Scope of feedstocks			Scope of bioenergy application	
	Agricultural	*Energy crop*	*Forestry*	*Heat*	*Power*
Belgium – Wallonia & Brussels Capital	√	√	√		√
Belgium - Flanders	√	√	√		√
Denmark			√	√	√
The Netherlands	√	√	√	√	√
The UK	√	√	√	√	√

Belgium, the Netherlands, and the UK apply legally binding sustainability requirements for solid biomass linked to the national support schemes, e.g. biomass that does not meet the sustainability criteria could in theory still be used, but would not be eligible for financial support or meet the national targets, and thus in reality would be very unlikely to occur. Solid biomass used in the focus countries needs also to be legal under the European Timber Regulation.

In Denmark, compliance with sustainability requirements is regulated through a voluntary industry agreement (sustainability criteria in the IA are semi-bindings), e.g. not directly linked to the support scheme(s) of sustainable biomass use. However, there are indirect subsidies for biomass energy in the form of (heavy) taxation of fossil fuels, that competes with tax-free biomass for heat production as well as direct renewable energy subsidy for electricity produced on biomass. These subsidies require that the biomass is uncontaminated (e.g. no waste or waste wood from processing).

The coverage of sustainability requirements including GHG emission reduction, land use criteria, and other sustainability requirements is most comprehensive in the UK, the Netherlands, and Denmark, while it is currently rather limited in Belgium (Belgian regulation is expected to be changed in 2017). This will be described in more detail in the following sections. Regarding the recognition of voluntary schemes, a number of voluntary certification schemes are already recognised in the UK, Belgium, and Denmark. The Netherlands is still in the early stage of benchmarking certification schemes. An overview of national sustainability requirements and possibilities for harmonisation are summarised on Table 2.3.

2.5.3 Evaluation of sustainability requirement comprehensiveness, assessment of scheme harmonisation and alignment

a. Greenhouse gas emission criteria

These cover GHG emissions in the supply chain with limited inclusion of carbon storage and land use change emissions (except for agricultural and waste residues).

- **Calculation tool:** BioGrace-II[105] is used in Denmark and the Netherlands to calculate GHG emissions in which information in various steps of the supply chain including cultivation, handling and storage of solid biomass, plant, inland and intercontinental transport is used. One example is the cultivation stage of energy crop where data of crop yield, moisture content, co-product, energy consumption and agrochemical are collected to estimate the emissions of CO_2, CH_4, N_2O which will be ultimately converted to CO_2 emission equivalent.

The UK has developed its own GHG emission calculator - the Biomass & Biogas Carbon Calculator which incorporates both the RED I approach and the BioGrace-II GHG calculation tools.[92] The operator must enter the GHG emission figure with options for known, exempted and unknown biomass. Where a GHG emission figure is entered, the system determines if the GHG emission criteria are met by reviewing the calculated figure against the relevant GHG emission threshold.

In Wallonia and Brussels-capital region, the GHG emisison accounting is based on the RED I-methodology and additionally includes emissions from the disposal of waste. In Flanders, GHG emissions are calculated considering the total amount of fossil energy spent in the supply chain.[100]

- **GHG emissions limits**: Compared to the 1990 baseline level, the Dutch and Danish requirements are the most ambitious requiring a 70% emission reduction as of 2016 to 75% in 2025. The UK require a GHG emission reduction of 60% from 2016 rising to 70% as of 2025. The limit increase is not necessarily constant over time in these three countries). In the Walloon and Brussels-Capital regions, the number of GCs issued depends on the emission reduction (the more reduction, the more GCs are issued), whilst in Flanders the number of GCs issued is based on fossil energy use along the supply chains.

Table 2.2 presents the GHG calculation methods, emission limits (over time), and timeline of implementation. These requirements are not closely aligned, and the requirements for data collection and transfer along the supply chain are not similar (e.g. the number of data required by Belgium is very large but very small for the UK). If requirements were agreed, harmonisation of the GHG emission calculation methodologies might be possible.

Table 2.2. Overview of methodologies to calculate GHG emissions in the four countries

	RO, RHI, CfDs - UK	GCs - BE		IA - DK	SDE+ - NL
		Wallonia & Brussels Capital	Flanders		
Calculation method	Own tool but based on BioGrace II & RED I methodology	Own method based on emission reduction, following RED I methodology	Own method based on fossil fuel use along supply chains	Verified calculation tool BioGrace II	Verified calculation tool BioGrace II
Limit (compared with 1990 baseline level)	60% (2016) 70% (2025)	No limit, but growing obligatory quota	No limit, but growing obligatory quota	70 % (2016) 75 % (2025)	70% (2016)
Timeline of implementation	Already implemented (Mar 2016)	Already Implemented since 2002	Already Implemented since 2002	Already implemented (Jan 2016)	Already implemented (2016)

Table 2.3 summarises harmonisation possibilities of and harmonisation level of various sustainability criteria and requirements. Regarding the reporting requirements, they are not the main focus of the article; therefore more details are provided in S.I.2.4.

Table 2.3. Summary of sustainability requirements and possibilities for harmonisation

	RO, RHI, CfDs RTFO - UK	GCs Wallonia– BE	GCs Flanders – BE	IA - DK	SDE+ - NL	Current Harmonisation Level	Harmonisation Possibilities	Note
I. Level of requirements	Legally binding to receive support	Legally binding to receive support	Legally binding to receive support	Voluntary	Legally binding (when implemented) to receive support	*Low*	±	Harmonisation possible between the Netherlands and the UK
II. Timeline of implementation	Mar 2016	Already implemented	Already implemented	Jan 2016	2016	*Medium*	±	Harmonisation possible between four countries
III. Sustainability Requirements Coverage								
Greenhouse Gas Emission:								
- Calculation method	√	√	√	√	√	*Medium*	±	Harmonisation possible between four countries
- Limit compared with 1990 level	√	√	√	√	√	*Medium*	→	Harmonisation possible between four countries
- Time of implementation	√	√	√	√	√	*High*	→	Harmonisation possible between four countries
Land Use:								
Sustainable forest management:								
Legal, sustainable sourcing & certification	√	±	±	√	√	*Low*	→	Harmonisation possible between the four countries

Table 2.3. Summary of sustainability requirements and possibilities for harmonisation

	RO, RHI, CfDs RTFO - UK	GCs Wallonia– BE	GCs Flanders – BE	IA - DK	SDE+ - NL	Current Harmonisation Level	Harmonisation Possibilities	Note
Forest productivity and well-functioning	√	±	±	√	√	*High*	√	Harmonisation possible between four countries
Biodiversity protection	√	±	±	√	√	*Medium*	√	Harmonisation possible between four countries
Ecosystems conservation	√	±	±	√	√	*High*	√	Harmonisation possible between four countries
Feedstock categories	√	±	±	x	√	*Low*	→	Harmonisation rarely possible between four countries
iLUC	*x*	*x*	*x*	*x*	√		*x*	
Other sustainability requirements								
Carbon debt	*x*	*x*	→	*x*	√		*x*	
Compliance with laws & local rights	√	±	±	√	√	*High*	±	Harmonisation likely possible between four countries<?>
Chain of Custody	√	±	±	√	√	*High*	±	Harmonisation likely possible between four countries

Table 2.3. Summary of sustainability requirements and possibilities for harmonisation

	RO, RHI, CfDs RTFO - UK	GCs Wallonia– BE	GCs Flanders – BE	IA - DK	SDE+ - NL	Current Harmonisation Level	Harmonisation Possibilities	Note
Mass balance	√	√	√	√	√	*Medium*	±	Harmonisation possible between four countries
Cascading use of biomass	*x*	*x*	→	*x*	→	*Low*	±	Harmonisation unlikely possible although possibly included in Flanders, Belgium, Denmark and the Netherlands
IV. Recognition of international voluntary certification schemes	√	±	±	√	→	*Medium*	±	Harmonisation possible between the four countries
V. Sustainability reporting requirements								
Station capacity	√	√	√	√	√		*x*	
Reporting procedure	√	√	√	±	√	Medium	→	Harmonisation possible between the four countries

Legend

Included in the national scheme
± Partly Included in the national scheme
→ Plans to be included in the national scheme
x Not included in the national scheme

Harmonisation is possible
→ Possible harmonisation in the future
± Harmonisation might be reached
x Harmonisation not possible

b. Land use

Land use related criteria are considered based on the UK approach[98] covering SFM used for woody biomass; feedstock categories used for biomass that is neither wood nor derived from wood; and iLUC for all biomass types.

- **Sustainable forest management**: The main issues related to SFM requirements were investigated including legal, sustainable sourcing & certification; forest productivity and well-functioning; biodiversity protection; and ecosystems conservation as the three main sub-criteria of sustainable forest management requirements, which are defined in the national and voluntary schemes.

In general, Denmark and the UK require that forest residues from nature and landscape management (with no difference in requirements for round wood, forest residues or secondary feedstocks) only need to comply partly with SFM requirement to ensure soil quality to be maintained and where possible improved. Belgium (both Wallonia and Flanders) and the Netherlands have clear definitions of various residues (primary, secondary and tertiary, see S.I.2.2) and in general, they do not need to comply with requirements of carbon and land use changes. However, residues from nature and landscape management as well as from agriculture need to comply with sustainable management criteria.

For wood or derived from wood (other than an energy crop), the requirements below need to be taken into consideration.

+ Legal, sustainable sourcing & certification: The UK RO mechanism states that independent certification of the wood by any of the forest certification schemes that cover the RO sustainable forest requirements or evidence of legality as required by EU Timber Regulation (EUTR) can be used (Category A, see S.I.2.2). Evidence that the wood fuel originates from a legal and sustainable source can also be provided in the form of alternative/bespoke documentary evidence that provides sufficient assurance that the source of the wood is legal and sustainable (Category B, see S.I.2.2). The Danish requirements for sustainable biomass follow the UK Timber Standard as clarified in its Industry Agreement.

In Wallonia and Brussels-Capital, a number of requirements for sustainable wood are currently being discussed, but it is uncertain what requirements will be included. In the Dutch SDE+ scheme, large forest management units (≥ 500ha) need to demonstrate compliance with SFM criteria at the forest level as of 2016. For biomass from SFM units (<500 ha), certification is currently accepted at the regional pellet mill level. In Belgium, proof of legal and sustainable sourcing and production of biomass is also required to 90% of the total biomass used.

Communication with Danish policy makers indicated that the Danish IA would be further developed, but it is not clear to what extent of comprehensiveness. Harmonisation seems only possible to a very limited extent, as the Dutch rules go into far more details than the UK and Danish requirements.

+ Forest productivity and well-functioning: the UK RO requires that productivity of the forest, ecosystem health and vitality are maintained. Similarly the Danish IA states that the forests must be healthy and well-functioning, its productivity and ability to contribute to the global carbon cycle must be maintained. The Dutch SDE+ requires, health and vitality of the forest must be maintained and where possible enhanced. It can be seen that in principle, these requirements are closely aligned, however wording and statements need to be discussed and agreed by national policy makers and relevant stakeholders. No requirement is included in the Belgian mechanisms.

SFM systems such as FSC, PEFC, SBP, and SFI could be used to prove the compliance with these requirements in the UK and Denmark. The SFM schemes, which are already recognised in other countries, might also be accepted in the Netherlands as stated in the draft verification protocol; therefore harmonisation might be possible among all four countries.

+ Biodiversity protection and ecosystems conservation: These requirements are part of the timber standard and feedstock categories included in Denmark, the UK, and the Netherlands. The UK legislation requires that harm to ecosystems is minimised and biodiversity needs to be maintained; and the Danish IA states that fundamental conditions of the ecosystem must be preserved. The Dutch SDE+ requires that biodiversity, high conservation value areas, the regulating effect, and the quality of the forest must be maintained and where possible enhanced. The Belgian mechanisms do not require suppliers and generators to provide proof of sustainability but they encourage solid biomass suppliers and bioenergy generators to include these requirements in their reporting.[106,107]

In summary, the requirements regarding biodiversity protection and ecosystem conservation in the four countries are not the similar. Alignment of these requirements would be possible among the four countries if policy makers agree on the terminology and level of details regarding biodiversity protection and conservation.

- **Feedstock categories (**all for types of biomass**)**

+ Definition of feedstock categories*:* The UK RO states that biomass cannot be obtained from land that at any time during or after January 2008 was land designated for protecting nature; a highly biodiverse grassland; peatland and a continuously or lightly forested area. Similarly, the Dutch legislation requires biomass not to be sourced from permanently drained land that was classified as peatland on 1 January 2008, from land that was converted from a wetland to an alternative. The Dutch legislation additionally requires that biomass is not sourced from production forests converted from natural forest after 31 December 1997.

Wallonia and Flanders have a similar definition of biomass feedstock categories including waste, residues, products, and co-products but there are no further details. Information in the UK and the Netherlands is much more comprehensive. The Danish IA does not have requirements for biomass originating from agriculture and bioenergy crops.

+ Reporting requirements linked with feedstock categories & sustainability criteria*:* Reporting requirements as a proof of sustainability compliance with national schemes are clarified in the four countries. Depending on different feedstock categories, the degree of reporting requirements differs significantly across countries. In the UK, waste and biomass wholly derived from waste are exempted from land use change and GHG emission criteria, whilst residues from agriculture and forestry are required to be included in annual reporting for land use change and partly for GHG emissions criteria (only emissions during and from collection and processing need to be reported). Biomass products and co-products[g] are required to comply with land use and full life-cycle emissions criteria.

In the Netherlands, reporting requirements are specified for various biomass feed-stocks. All woody biomass need to comply with SFM requirements, carbon and land use change[h]. Residues from agriculture, nature and wastes only need to comply with GHG emission balance and chain of custody criteria.

There are various classifications of biomass feedstocks, and accompany reporting requirements are not equivalent in the Netherlands and the UK. One example is that the Dutch SDE+ requires carbon debt and iLUC to be applied for woody biomass which is only from large forest units. Another example is that the UK RO has developed feedstock categories for various biomass sources whilst the Danish IA only focuses on forest biomass. The Dutch SDE+ includes land sustainability requirements also for solid biomass originating from agricultural waste and residues. Full harmonisation of these criteria is not yet possible and can only be achieved if policy makers have a clear definition of land categories and agreement of what biomass sources need to demonstrate sustainability compliance.

c. Other sustainability requirements (for woody and agricultural biomass which are not residues)

- **Indirect land-use change**: The Dutch SDE+ requires that biomass sourced from new bioenergy plantation systems that were planted after 1 January 2008 must have a demonstrably low iLUC risk in which risk can be calculated following the Low Indirect Impact Biofuels methodology.[108] The UK legislation does not include iLUC criteria and it is briefly mentioned in the Danish IA that there are currently no agreed methods for calculating compliance with the requirements relating to carbon cycle, maintenance of forest carbon stock, iLUC and indirect wood use change (IWUC). The Danish industry aims to develop methods to document and formulate more detailed criteria.[103]

Harmonisation of iLUC criteria is unlikely possible in the future as agreement on iLUC definition and risk assessment are still being debated in the focus countries.

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g *Biomass from co-products (e.g. sawdust) has to meet the sustainability requirements of round logs in both the UK and DK as it is easier to demonstrate compliance for round logs than sawdust.*

h *woody biomass from small forest management units of less than 500 ha do not need to compliance with indirect land use change requirement*

- **Carbon debt:** The Dutch SDE+ indicates that the forest management units where the all type of wood are sourced, must be managed with the aim of retaining or increasing carbon stocks in the medium or long term.[108] The Dutch carbon debt criterion focuses mainly on forest stumps (biomass is not sourced from stumps unless these stumps had to be removed from the site for reasons other than wood or biomass production) and harvested forest (in which less than half the volume of the annual roundwood harvest is processed as biomass for energy generation).

The carbon debt criterion is briefly mentioned in the Danish IA[103] but is not yet defined in the UK, Belgium, nor on international level. It is clear that the level of compatibility between the four countries is currently very low, and that harmonisation of criteria covering carbon debt is unlikely in the near future.

- **Compliance with related laws & local rights:** The Danish IA requires compliance with local laws regarding social, work rights: child labour and discrimination are not permitted. The Dutch SDE+ has defined a compliance requirement with not only local but also international laws and regulations that might be more complex to comply with, whilst the UK has requirements of labour, welfare health and safety at only local and national level. This criterion is not clearly defined in Belgium but cross-compliance with related legislation is encouraged.[106] However, each country requires compliance with the EUTR and therefore this should confer a high level of harmonisation in terms of compliance with related laws and local rights.

- **Chain of Custody (CoC):** The Dutch SDE+ defines that a chain of custody must be in place that covers the entire chain from the first link to the bioenergy producer and that the CoC also quantifies the GHG emissions of each individual link in the supply chain[108] (more information see S.I.2.2). The GCs in Flanders and Wallonia/ Brussels-Capital define that CoC is the traceability system for tracking biomass inputs from their production to the inputs at the power generation site and that via the traceability system, it is possible to know information in each step of the chain. The UK legislation defines CoC for both agricultural and forest products as the traceability in the supply chain from raw material to end products.[98] The CoC requirements are not yet defined in the Danish IA but it will likely adopt those of the UK.

Definition and requirements of the CoC are rather similar in Belgium, the Netherlands and the UK, and if policy makers would agree with the CoC definition, harmonisation might be possible between the three countries.

- **Mass balance**: The UK legislation permits the mass balance method to be used where different consignments of biomass are mixed at the generating station or at any point in the supply chain. A minimum of 70% of the mixed biomass needs to meet all sustainability requirements and the remaining 30% the legality requirements. The Danish IA follows the UK approach.

The Dutch SDE+ scheme has similar requirements that the mass balance requirements may apply to the mixing of biomass, and hence a single physical delivery could also include biomass with different properties. Also in Belgium, mass balance is used in order to ensure that green energy produced from solid biomass is achieved.

A harmonisation therefore may be possible among the focus countries if policy makers could agree on the mass balance approach.

- **Cascading use of biomass**: There is no consideration of biomass cascading use in the UK whilst it will likely to be required in Flanders but there is not yet a consensus on the definition of cascading.[109] Consultation with policy makers from Wallonia and Denmark has revealed that this criterion may be included in their national schemes in the future but it is not yet clear to how and what extent.

Harmonisation of cascading requirements is not yet possible and it is still difficult to predict how cascading use of biomass will be defined in different countries as well as how the level of sustainability requirement is agreed.

d. Recognition of voluntary SFM schemes:

Biomass suppliers and generators may use more than one voluntary scheme or a combination of a voluntary schemes and collect other information (some examples are shown on Table 2.4).[98] The suppliers and generators can also use voluntary schemes approved by the EC to demonstrate compliance with the national sustainability criteria and requirements.[103,106,107,110] Use of these schemes as such may help to reduce cost burden and complexity in providing evidence of sustainability compliance of solid biomass where sustainability criteria are required and may therefore facilitate biomass trade from various sourcing regions.

The SFM systems such as FSC Controlled Wood (Company), FSC Controlled Wood (Forest Management Enterprise), PEFC Controlled Sources, SFI Fiber Sourcing and SBP (which also uses FSC/ PEFC/ SFI standards) are recognised in the UK for many of land related criteria and SFM requirements. Belgium and Denmark have also indicated their acceptance of FSC, PEFC forest certification and SBP certification as well as verification from an organisation that is EU-approved,[111] but it is not clear regarding the levels of sustainability criteria inclusion and comprehensiveness that meet national requirements.

In the Netherlands, FSC 100% compliant, PEFC 100% compliant can be used to demonstrate compliance with the sustainability requirements regarding soil quality, carbon and sustainable forest management as well as supply chain management. In addition, the Dutch SDE+ scheme only recognises the FSC Controlled Wood and PEFC Controlled Sources for the controlled biomass compliance; the SBP for supply chain management. And none of the SFM reviewed schemes covers residual flows from nature and landscape management (biomass animal and arable products), biogenic waste and residual products as set in Dutch sustainability requirements or residues from agriculture; aquaculture and fisheries as set in the UK legislation. In principle, comprehensiveness and coverage of sustainability criteria in the SFM schemes will decide the level of recognition in national sustainability support systems.

The SBP standard 5 defines the methodology for collection and communication of GHG emission data along the supply chain enabling generators to demonstrate compliance to their regulators. The SBP Standard 6 provides a mechanism for the certification of the GHG emission calculation of the generator. The PEFC has published a draft mechanism for the transfer of GHG emission data along the supply chain of solid biomass. The FSC Carbon Footprint Procedure aims to provide a method to calculate carbon footprint, and indicate possibilities to be acknowledged as the GHG criteria compliance in those countries. The procedure is however, not yet implemented.

Table 2.4. Summary of proof of compliance of SFM certificates in the UK (adapted from the UK 2015 benchmarking exercise against the feedstock categories for woody biomass)

Name	**FSC Controlled Wood (Company)**	**FSC Controlled Wood (Forest Management Enterprise)**	**PEFC Controlled Sources**	**SBP**	**SFI Fiber Sourcing**
(Benchmarked version)	FSC-STD-40-005 (Version 1-0)	FSC-STD-30-010 (Version 2-0)	PEFC ST 2002:2013 (Controversial sources)	SBP March 2015	SFI Fiber Sourcing 2015-2019
Wood fuel criteria					
Consistency with the Forest Europe SFM Criteria	Not assessed as these criteria already show compliance			Yes	Yes
Standard setting process	Yes	Yes	Yes	Not assessed as these criteria already show compliance	
Standard change process	Yes	Yes	Yes		
Harm to ecosystems is minimised	Not covered: except for the protection of biodiversity.			Yes	Partial
Productivity is maintained	Not covered	Not covered	Not covered	Yes	Yes
Health and vitality of ecosystems is maintained	Partial	Partial	Partial	Yes	Partial
Biodiversity is maintained	Partial	Partial	Partial	Yes	Partial
Compliance with laws relating to labour, health and safety, welfare of workers	Partial	Partial	Partial	Yes	Partial
Land-use rights, grievances and disputes, health and safety and workers' rights	Partial	Partial	Partial	Yes	Not covered
Regular assessment	Yes	Yes	Yes	Yes	Yes
Regional risk based approach					
Definition of a region	Yes	The assessment of a regional risk-based approach is not applicable	Yes	Yes	Yes
Woodfuel must be traceable back to a supply base within the region	Yes		Yes	Yes	Yes
Evidence must demonstrate a low risk of non-compliance	Yes		Yes	Yes	Yes
Audit and certification	Yes	Partial	Yes	Yes	Yes
Accreditation	Yes	Yes	Yes	Yes	Yes
GHG emissions requirements					
Calculation method	Draft available but not yet recognised	Draft available but not yet recognised	Draft available but not yet recognised	Available but not yet recognised	No

In conclusion, voluntary certification systems are partly recognised in the national schemes (these systems do not meet requirements such as iLUC and carbon accounting). However the SBP scheme is aligned with most of the UK sustainability criteria, also the FSC 100% compliant and PEFC 100% compliant are fully recognised in the Netherlands (but some individual PEFC national standards will benchmarked and might not be accepted).[112] In order to be recognised on various national legislation, voluntary certification schemes for sustainable solid biomass need to include additional sustainability requirements that are not easily achieved due to different focus and specific requirements of various government schemes.

2.6 CONCLUSIONS AND RECOMMENDATIONS

2.6.1. Conclusions

The article has shown a similarity of sustainability criteria that are covered in the national support schemes, but that the definitions and level of ambition differ. There are only a limited number of sustainability requirements that are compatible and /or could be fully harmonized. These focus on woody biomass including biodiversity protection, ecosystems conservation, forest productivity and well-functioning forests. This paper also found that the Dutch SDE+ scheme has a number of sustainability requirements that are not included in the other countries, and is therefore likely to hinder Dutch generators importing biomass.

Chain of custody: The Dutch requirements are more detailed and extensive than for other countries, thus create challenges in demonstrating compliance, and will limit the trade between different markets. Those requirements will also lead to difficulties in aligning the sustainability criteria defined in the Dutch SDE+ with those in other national schemes.

GHG emission thresholds and saving approaches: In the four countries, GHG emission thresholds and saving approaches that are not aligned. Varying threshold levels are not necessarily a barrier to trade, but they could lead to leakage, for example all biomass that meets the high threshold level will be imported by country A, while country B with a lower threshold will import biomass with lower GHG emission savings. If solid biomass leakage occurs, it limits the effectiveness of national support schemes dedicated to biomass sustainability in the country with stricter sustainability requirements.

The exact requirements for data collection of GHG emissions and other sustainability issues are only complete in the UK and the Netherlands, whilst information is not fully comprehensive in Belgium and Denmark. However, there is a possibility that the GHG emission calculation methods and thresholds could be aligned as the national schemes all base their GHG emission calculator on the RED I's calculation method. The distinction between different biomass feedstocks is decisive in determining whether certain types of biomass meet the requirements of GHG emission reduction in each country.

Carbon debt and iLUC: Besides requirements for GHG emissions, criteria to limit the risk of decreasing carbon stocks in the medium or long term as well as leading to iLUC are currently being introduced and tested in the Netherlands, and Denmark is considering introducing these criteria in the future.[103] It remains to be seen whether the four countries will choose similar approaches, and whether these can then be harmonized.

It is noted that in all four countries, sustainability criteria and requirements apply only to large-scale industrial use whilst use of wood pellets for heating in households (a substantial share of the total wood pellet demand in Europe) are not in place due to the difficulty in monitoring small-scale users.[111] Similarly, there is a lack of comprehensive sustainability criteria for solid biomass used in other sectors (both traditional such as paper and construction, and new such as bioplastics and biochemical),[92] although legality of wood based products in the EUTR and sustainability are included in some cases (e.g. Timber Procurement Policy in the UK or Sustainable Timber Procurement in the Netherlands). If sustainability requirements are only mandatory for (a limited number of) bioenergy applications, but not for others material purposes, this may lead to leakage, for example the use of unsustainably produced feedstocks for residential heating or biochemical production. At the same time, inclusion of criteria for GHG emission reduction, iLUC, carbon debt etc., for other end uses would further complicate the issues and further reduce the chances to align and harmonise the national requirements.

Finally, while the data and information supporting this study were collected with great care and verified with interviews with experts, the accuracy of all data presented in this report cannot be fully guaranteed. Also, over the course of the study (January 2014 – December 2016), policies have changed, and are likely to continue to do so in the future. Therefore, the results and implications of this study may change even in the short term.

2.6.2 Recommendations

In the short term and outlook, opportunities for harmonisation will depend on policy makers and other willingness of stakeholders to change existing legislation and support schemes to allow for more harmonisation. At the same time, different stakeholders pursue different interests in the focus countries, leading to different outcomes (as illustrated in particular by the Dutch case), thus limiting the opportunities for harmonisation further. Ultimately, a decision at EU level regarding the use of GHG emission calculation tools, data collection and default values for biomass types would be best for biomass suppliers and producers, as it would likely bring greater consistency. Ideally, a single authority such as the EC Joint Research Centre could provide information related to GHG emissions. This would already lead to a basic level of harmonisation.

In 2015, the EC issued the Energy Union Strategy and announced that it would only come forward with an updated bioenergy sustainability policy as part of a renewable energy package for the period after 2020. In late 2016, in its proposal for the new directive on renewable energy, the EC indicated that existing various national support schemes have led to a sub-optimal situation, and this has in turn negatively impacted investor confidence.[93] The proposal includes some principles for support schemes that Member States can adopt for the protection for investors against retroactive changes and also proposed sustainability criteria (developed for forest biomass alongside a requirement to include emissions of land us, land use change and forestry in national commitments under the Paris Agreement) that should be considered and included as necessary at the EC level. The proposal will be debated in the European Parliament and Council in 2017, and it is still unclear when a final agreement on such general sustainability criteria can be achieved.

Furthermore, regular structured information exchange and discussion among policy makers and industry on ongoing legislative development in all countries implementing national requirements is recommended as this may aid future harmonisation or at least avoiding more divergence. As legislation for solid biomass sustainability is being drafted and updated, dialogue between those stakeholders (policy makers, industry, academics, NGOs and others) should be organised on a regular basis and at an international level to achieve common understanding on sustainability requirements for solid biomass, as well as to increase the possibilities of harmonisation. More discussion on a number of issues such as carbon debt, iLUC and biomass cascading could also be useful to formulate practical yet comprehensive sustainability criteria.

Regarding cascading use, solid biomass used for heat and power generation is generally low value and a large proportion of woody pellets are imported, particularly from North America.[113] It is difficult for the US suppliers to comply with the cascading requirements as it is still unclear what criteria are used to measure and how cascading will be implemented. A clear definition for cascading is therefore recommended. In general, agreement on common criteria definition, the level of sustainability requirement should be achieved first among various countries before specific legislation could be designed and applied for in a particular country. Awareness of requirements and guidance for biomass suppliers and generators is also important to enable them to demonstrate compliance.

In addition, the development of a harmonised certification scheme that could be used to meet criteria in all countries is recommended. The SBP is currently the only certification scheme that was developed to meet this goal, and is recognized in the UK, Denmark, and is being used to demonstrate compliance in Belgium. Given the anticipated changes in the four countries, its standards will likely have to be adapted and extended. Much effort is required including consultation and discussions with national policy makers and related stakeholders to structure such a comprehensive certification system.

One particular issue is the amount of woody biomass that may be sourced from SFM-certified forests at acceptable costs – which is probably limited. The UK risk based approach seems to be working as a (at least temporary) solution to demonstrate sustainable biomass production for export to the EU. Also the Dutch system allows for such a risk-based assessment, but has already put a sharp timeline that is will only be possible for small forest owners and only until 2020. Given the limited amount of certified biomass currently available in many sourcing regions, and the fact that this is not likely going to change rapidly in the short term, it is recommended that national policy makers develop policies that will incentivise the uptake of SFM certification in the sourcing regions in the short-to-medium term, in particular to collaborate with forest owner for solid biomass certification in the South East US. Solutions such as group certification for smallholders or provision of an economic incentive (which may somehow distort market prices) could be ways to increase the uptake of SFM certification, and at the same time also to discuss and determine which risk levels are acceptable on the short- and medium term. Risk-based approaches to demonstrate compliance with e.g. SFM and legal requirements also carry challenges. Having agreement between countries as to what risk levels (and thus ultimately which sourcing regions) are acceptable would also reduce trade barriers and prevent leakage effects.

SUPPLEMENTARY INFORMATION

S.I.2.1. TERMINOLOGY

To clarify the study focus and also to align different sustainability issues identified in the national support and voluntary schemes, the terms sustainability requirement and criteria are defined. They will be used intertwined.

Sustainability requirement: are the overall sustainability goals that the national schemes require biomass producers and suppliers to comply with. They include statements that do not have specific details but aim toward sustainable use of solid biomass. For example, the annual average GHG emissions should meet or is below the target set by the national scheme.[108]

Sustainability criteria: are more specific compared to sustainability requirements. The criteria indicate details for solid biomass suppliers and generators to comply with national sustainability requirements. For example, (for most solid biomass generators) the relevant GHG emission threshold is 79.2 g CO2eq/MJ electricity.

S.I.2.2. DEFINTIONS OF SUSTAINABILITY CRITERIA

- *Green house gas emission reduction*: Each country requires a minimum emission saving. The GHG emission criteria were evaluated based on the calculation method, emission threshold and timeline of implementation.

- *Land-use criteria*: includes sustainable forest management requirements applied for wood or biomass derived from wood as well as feedstock categories (which in principle follows land criteria defined in the RED I) applied for various types of solid biomass

- *Forest residues*: are defined in the Dutch SDE+ scheme and in Belgian mechanisms including primary residues (biomass that is processed directly on the logging site, e.g. logs, wood chips, pellets and harvest residues); secondary residues (residual products from wood processing e.g. sawdust, bark etc.); and tertiary residues (post-consumer residues)

- *Category A* (as defined in the UK RO) is where a certification scheme claim can meet the legal and sustainability requirements. Schemes are benchmarked to check if their claims meet the requirements – currently only the FSC, PEFC and SBP are recognised.

Category B means that evidence can be provided which is not (just) certification. Essentially Category A evidence is a shortcut but Category B allows generators to use other evidence if they don't have certified biomass.

- *Carbon debt*: is defined generally as the temporal imbalance between carbon emission and carbon sequestration. The carbon debt needs to be 'paid back' before the forest bioenergy system is a net contributor to climate change mitigation.

- *iLUC*: occurs when an existing plantation is used to cover the feedstock demand of additional bio-energy production. This displaces the previous productive function of the land (e.g. food production) which may cause an expansion of the land use for biomass production to new areas (e.g. to forest land or to grassland) if the previous users of the feedstock (e.g. food markets) do not reduce their feedstock demand and any demand-induced yield increases are insufficient to produce the additional demand.

- *Cascading use of biomass* is defined as material use of wood should be prioritized over energy use of wood.[114, 115]

- *Mass balance* (as defined in the UK RO) is a system in which sets of sustainability characteristics remain assigned to consignments. The sum of all consignments withdrawn from the mixture is described as having the same sustainability characteristics, in the same quantities, as the sum of all consignments added to the mixture. A party in the chain of custody cannot sell more output with certain biomass data than its sourced input with the same biomass data.

- *Chain of Custody* (CoC) (as defined in the Dutch SDE+) must be in place that covers the entire chain from the first link (forest management unit for solid biomass from large forest management unit; or pellet mill from small forest management unit) to the bioenergy producer.

- *Risk based approach* is designed to helps solid biomass buyers and suppliers provide evidence for compliance with the feedstock categories without the use of forest level certification. It a concept developed by the UK BEIS as an adaption of the Timber Procurement Program requirements for solid wood to biomass.

- *Reporting requirements*: relate to biomass suppliers and generators reporting against sustainability criteria defined in national legislation and schemes.

S.I.2.3. SUMMARY OF CONSULTATIONS WITH STAKEHOLDERS ON NATIONAL SCHEME UPDATE AND SUSTAINABILITY REQUIREMENTS

S.I.2.3.1 Outcomes of general questionnaire of September 2014

Different questionnaires were designed for industry and policy makers. Of eleven energy utilities contacted, seven provided feedback. Respondents recognised the importance of mandatory support schemes linked with sustainable solid biomass use at a national level. The influence of national support and voluntary schemes for sustainable solid biomass is limited as it is required only within the boundary of a single country, hence the utilities indicated their expectation of a European-wide set of sustainability criteria covering all requirements and a harmonized scheme. A mandatory set of sustainability criteria was identified as essential, however respondents emphasised that the criteria should be similar in various schemes. The requirement level of sustainability criteria in national schemes in each country was also different, therefore procedures for the application of certified biomass are extremely complex to implement for utilities which have operations in multiple European countries. This lead to challenges of higher time and resource cost, more regulatory burdens and trade barriers.

Policy makers were contacted to share their updates on national schemes. The UK policy makers provided relevant data sources and recent references for scheme establishment and stated that large suppliers were well advanced in reporting sustainability requirements but the situation is more difficult with small suppliers. The government had helped solid biomass generators by providing guidance documents and offering two years of voluntary reporting against the GHG emissions reduction in RO 2015 (which cover the sustainable forest management for wood-fuel, one type of solid biomass). Policy makers in Belgium stated that regarding Green Certificate requirements procedure and costs are accepted by industry as legislation was developed with consideration to industry expansion. In Denmark, the government recognised efforts of the industry to form the Industry Agreement and in the Netherlands, the Energy Accord was being finalised (at the time of this communication) through the negotiation of energy utilities with NGOs. Consequently, generators could be considered to be actively engaged in the implementation of sustainability criteria and reporting requirements.

Regarding the recognition of international voluntary schemes and how their sustainability criteria match the national systems, policy makers reported that a number of SFM schemes such as PEFC and FSC were already recognised in Belgium and Denmark, however they lack some criteria regarding GHG emissions in the supply chain. Policy makers mentioned that if there is no establishment of EU-wide sustainability criteria, there is a risk that countries which do not have criteria become a sink for cheaper, less sustainable biomass, therefore negating the carbon and wider sustainability benefits sought by other countries. They also emphasised that there were obvious benefits to industry from a harmonised scheme. A full study and impact assessment of the costs and benefits of harmonisation at any level would be needed to justify the proportionality of such action, including assessment of the current level of cross-border business. Policy makers indicated their support on a EU-wide harmonisation of sustainability criteria, however additional work at EU level needs to be completed such as clarification on how to better manage carbon stocks.

S.I.2.3.2 Outcomes of the international workshop "Potential for Harmonisation of National Sustainability Certification Schemes for Solid Biomass'', November 2014

This workshop presented the preliminary results of a questionnaire and debated the possibilities for and bottlenecks of alignment. Participants agreed that GHG calculation methodology was not a major obstacle. They pointed out that a single methodology would be preferred with an approach that is comprehensive (taking into account requirements from various schemes), clearly defined, and simple to implemented. Participants specified that the acceptance of different voluntary certification systems is very important; however a full set of criteria needs to be developed so that they could be recognised by the national schemes. Determining an appropriate level of sustainability requirements was identified as significant, as this will help engage NGOs in the development of sustainability criteria.

The participants also identified that for the UK, Belgium, and Denmark, a risk-based approach (see definition in Supplementary Information 2.2) as a proof of sustainability compliance is deemed acceptable, at least for a limited share of the total feedstock supply. For the Netherlands, with its on-going negotiations (at the time of this workshop) it seemed clear that a risk-based approach could only be a starting point on a growth-path towards full stand level certification. NGOs stated that they favour the Forest Stewardship Council (FSC) as an SFM system, although there was an on-going discussion on the FSC risk-based approach for controlled wood. Stakeholders said that a risk–based approach covering the catchment area of a specific pellet mill could be applied to low risks (e.g. child labour in the US). Other risks, which were not clear at state level or differed widely, e.g. conversion of natural stands to plantations, may have to be monitored at a more discrete spatial level (for example, at a pellet or even at a stand-level if it is proven that there is a high risk for conversion in a catchment area).

Stakeholders stated that the cascading use of biomass was still under discussion in the focus countries and data on trade flows, prices and end-uses, incentives and subsidies for the use of waste wood needed to be better mapped. Some policy makers also mentioned that the emerging Dutch concepts on carbon stock might influence on-going development of legislation in other countries. A number of participants agreed that scientific proof would be required to investigate what the different risk levels of carbon debt are, and what types of biomass should be covered. Participants also stated that the definition, measurement, and management of carbon stocks in the forest are crucial. According to them there would probably currently be sufficient sustainably produced material as well as in the future to meet the sustainability criteria.

S.I.2.3 Outcomes of questionnaires on "Implementation of Sustainability Assurance Frameworks": Ongoing Developments and Pending Issues" of February 2015

As the GHG emission calculation and SFM certification are considered the two main topics, a single set of questionnaire was designed then sent to both policy makers and industry to obtain their opinions on these two subjects.

- GHG emission calculation:

Stakeholders all noted that a harmonised approach to the calculation at EU level should be based on the BioGrace framework. Stakeholders recommended a set of harmonised definitions of feedstock at EU level and they also proposed a set of default values developed by the Joint Research Centre. At the time of the workshop, there was no consensus on science & methodologies regarding the GHG emission footprint, but GHG emission calculation can be facilitated by complementary systems such as SBP. Participants also mentioned that the mass balance approach considered feasible and can be used to demonstrate sustainability of biomass.

- SFM certification:

Stakeholders suggested that national policy makers consult with voluntary certification scheme representatives regarding certification process. The consultation would facilitate evidence of solid biomass certified by recognised SFM schemes can be used to demonstrate compliance with national schemes. Consultation was considered important to avoid non-alignment of similar sustainability criteria from across schemes.

Additionally, industry recommended considering regional risk assessment instead of forest level certification to demonstrate sustainability. In general, most of the stakeholders agreed that each scheme has been developed for specific purposes & specific market; therefore it is difficult to identify a preferred system, although SBP was developed specifically to meet the needs of national regulators in determining biomass sustainability. Industry preferred that there should be no change in the percentage of SFM certified biomass over time and stated that the bioenergy sector is a minor player in the forest market. Most stakeholders mentioned 100% legal with 70% certified min + 30% max controlled wood (or equivalent) would be feasible and they also added that non-SFM certified material should also demonstrate sustainability. Specific FSC, SBP, and PEFC systems already offer mass balance and this approach proves to work properly.

S.I.2.4 Outcomes of international Policy Maker Workshop: "Implementation of Sustainability Assurance Frameworks": Ongoing Developments and Pending Issues" of March 2015

- GHG emission accounting: methodologies and actual verification

The JRC is in charge of the GHG emission calculations for the bioenergy systems. They collected the data (which are open for adjusting) for each process in the supply chain from peer-reviewed publications and consultations with stakeholders. The acquired and converted data is then inserted into a calculation tool that applies the methodology set in the staff working document (SWD) and represents average European conditions to produce the final typical value. Based on that typical value, a default value can be finally determined.

The BioGrace II tool was introduced to demonstrate how the EC default values on solid and gaseous biomass were calculated for electricity, heat, and cooling. It followed the EC/JRC methodology and was intended to further develop a user-friendly tool for making actual calculations as well as contributed to a harmonised tool within Europe.

- Debate on sustainable forest management:

A US representative said that the US Southeast is a key region of pellet export to the EU, and European buyers might have influence on the US forest certification. Therefore if there were a need to source and certify sustainable solid biomass, the US market may adjust to the market trend. The risk-based approach was mentioned as applicable to assess risk of sustainable solid biomass in the whole supply chain. The quality of self-risk assessment varied however from country to country.

S.I.2.3. REPORTING REQUIREMENTS

S.I2.3.1 Reporting requirements

a. Station capacity

In the UK, operators of heat and power stations with a > 50kW but ≤ 1 MW must submit annually profiling information on the sustainability characteristics of their biomass, including biomass type and form, biomass quantity, country of origin and purchase.

The sustainability reporting in the UK is obligatory for generators with a capacity 1 MW of electricity equivalent or above. As identified in the Danish Industry Agreement, only utilities with a capacity above 20 MW are required to annual sustainability documentation; it is that 80-90% of solid biomass is used in utilities with this capacity.[103] In the Netherlands, sustainability requirements have been formulated for the co-firing and co-gasification of biomass in coal-fired power plants (≥ 100 MW), and large-scale heat projects where steam is generated from the burning of wood pellets (≥ 5 MW).

In Belgium, the GCs are granted for 456 and 217 kg CO_2-emissions avoided in Wallonia and Brussels-Capital region respectively, and the GC for all types of included renewable sources is limited to 1 certificate per MWh of produced electricity in Flanders. In addition, the amount of minimum GC share (quota) in total electricity will be increased gradually, e.g. in Wallonia, the total quota was 13.5% in 2011 but this will increase to 37.9% in 2020. Other requirements are also different in the three regions. In Brussels-capital region, the CO_2 savings of the plant shall amount to at least 5% compared with conventional installations. In Wallonia, the number of certificates depends on the amount of electricity generated; one certificate is issued for every MWh divided by the amount of CO_2 saved. In Flanders, the VREG calculates annually the GC number submitted by each supplier in order to comply with sustainability requirements.

Table 2.5. Reporting requirements regarding biomass for heat and power generation capacity

	RO, RHI, CfDs - UK	**GCs - BE**	**IA - DK**	**EA - NL**
Generator capacity	≥ 1 MW	linked to annually increased quota of GCs	≥ 20 MW	≥ 100 MW: co-firing and co-gasification of biomass in coal-fired power plants ≥ 5 MW: large-scale heat projects

b. Reporting procedure

Annual reporting developed and verified by an independent third party is briefly mentioned in the Danish IA. The Dutch SDE+ system indicates the verification of data and sustainability claims to relevant body. The legal framework for the system is still under development. A transition period is in place until the new legislation enters into force. There is a procedure for companies that are required to demonstrate sustainability of the biomass before the end of the transition period in order to obtain an SDE+ subsidy.

They can use a number of temporarily approved certification schemes and the currently available Verification Protocol, which is specifically designed for the transition period.

In Belgium, in order to receive a grant of GCs in Wallonia, an accredited inspection needs to be prepared along with the application of compliance certification of the biomass installation. Information of audit content and report is provided to the authorities for biomass type and origin, energy consumption in the supply chain, mass balance, and chain of custody (CoC). In the Brussels-Capital region, there are no particular requirements for solid biomass generators and auditors; however proof of continuous increase of biomass as renewable resource for electricity generation is needed. Compliance with environmental quality is also a requirement for electricity generators but no information is found for audit timing. In Flanders, a proof of compliance needs to be submitted by electricity suppliers and is verified by the VREG to demonstrate compliance with minimum share of biomass for electricity generation. An independent verification body plays an important role to verify the biomass origin and processing, transport means, and energy balance of electricity generators in order to prove the efficiency of biomass production.

In the UK, to demonstrate compliance with sustainability requirements, operators need to engage with an independent auditor to collect information and/or use voluntary schemes as evidence for their annual sustainability audit. Information may lie with other parties in the supply chain and generators need to ensure that all parties have effective systems for reporting, obtaining, and retaining sufficient and appropriate evidence to support their data reporting. When submitting their report, operators will need to consider Ofgem guidance on sustainability criteria (Ofgem, 2016a). Evidence of compliance with an approved voluntary scheme can also be sufficient proof of compliance recognised for (Ofgem, 2016a).

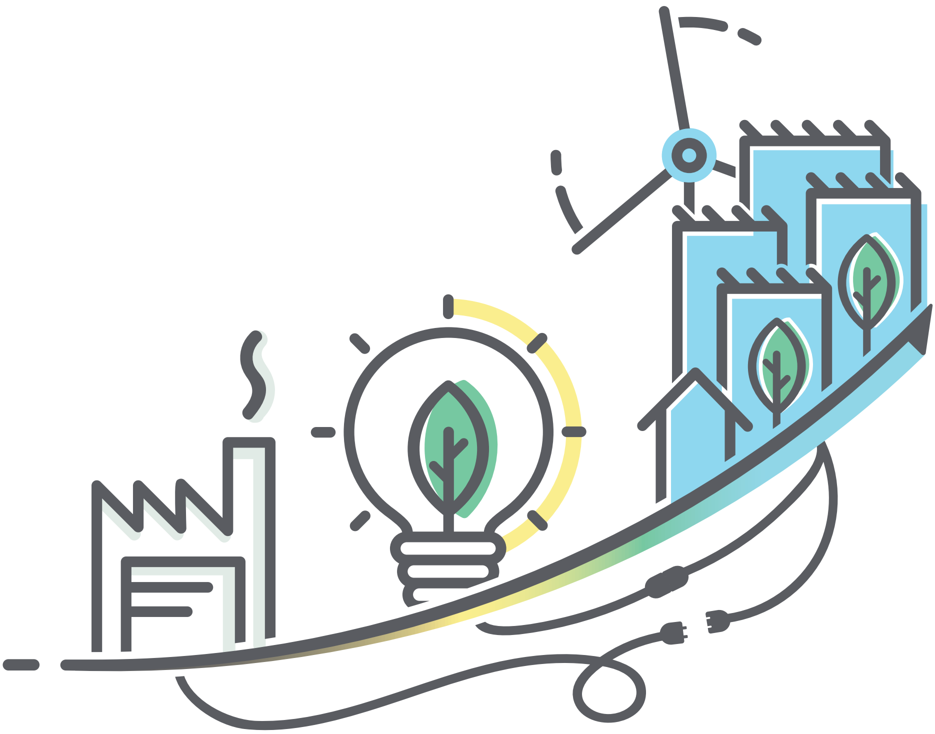
c. Harmonisation possibilities for reporting requirements

As explained, reporting requirements for heat and power generators are not equivalent in the four investigated countries. Regarding the requirements for heat and power capacity, the Belgian approaches are very different. The UK has stricter requirements for capacity of heat and power station than Denmark and the Netherlands. Harmonisation of this criterion is not possible.

Reporting procedure is only briefly mentioned in the Danish IA. In Belgium, the Netherlands, and the UK, requirements of reporting verification and audit are provided but with more detailed in the UK and the Netherlands. It is difficult to prediction the possibilities of harmonisation but information in the Danish IA and Dutch SDE+ indicates possibilities of harmonisation regarding verification by independent third party.

Table 2.6. Summary of harmonisation possibilities for reporting requirements

	Possibilities of harmonisation	**Level of harmonisation**	**Notes**
Station capacity	x		Harmonisation impossible as Belgium has different approach whilst station capacity differ between Denmark, the Netherlands and the UK
Reporting requirements linked with fuel classification and sustainability criteria	x		There are more sustainability criteria to be applied in the Netherlands which are still being debated in other countries
Reporting procedure	→	Low	Harmonisation is possible but depend on the agreement of verification level and audit requirements
Legend		√	Harmonisation is possible
		→	Possible harmonisation in the future
		±	Harmonisation might be reached
		x	Impossible harmonisation



3

Charting global position and vision of stakeholders towards sustainable bioenergy

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3.1 BACKGROUND

Bioenergy has an important role in the current and future energy landscape.[116] Many European Member States and other countries have recognized the role of bioenergy in increasing the share of renewable energy and reducing greenhouse gas (GHG) emissions, in helping countries to become less dependent on fossil fuels, and in making a significant contribution to the bioeconomy.[59,116–121] In the European Union (EU), energy from biomass and the renewable share of waste contributes to almost two-thirds of the primary combined renewable energy production today, and the absolute amount is expected to further increase slightly until 2030.[72,122] Other large economies have also emphasised the role of bioenergy on their policy agendas. In 2017, modern bioenergy accounted for about 50% of total global renewable energy consumption, and bioenergy is expected to be the largest source of growth in renewable energy consumption over the period 2018-2023, with an expected growth of 30% in this period.[121] The EU 2020 and 2030 renewable energy targets as well as country-level policies and energy efficiency will stimulate further the use of bioenergy in the continent.[120] Also in its latest 2018 report, the Intergovernmental Panel on Climate Change (IPCC) highlights that bioenergy use is substantial in 1.5°C-consistent pathways due to its multiple roles in decarbonizing energy use with or without a carbon capture and storage combination.[123]

The potential role of bioenergy in the transition to a sustainable low-carbon energy system is widely acknowledged by stakeholders in many countries and regions. However, the extent to which bioenergy should be deployed, under what conditions, what feedstocks should be used, and what end uses should be stimulated in the short-, medium- and long-term are seen differently by diverse stakeholder groups. According to various regional case studies, many stakeholders indicate recognition of the positive role of bioenergy in the current and future energy landscapes, and support bioenergy development if certain conditions are met; but many other stakeholders hold negative views on bioenergy if certain conditions are not satisfied.[64,65,72,124] However, those studies mainly focus on specific supply chains in regions or countries in Europe, the United States (US), and Asia.[65,67,124] Many of the stakeholders focus on specific aspects such as the challenges to governance of bioenergy sustainability,[64] social acceptance of energy issues,[69] or on a limited range of stakeholder groups, mainly the general public or consumers.[65,125] Those studies have answered questions related to relatively isolated issues such as feedstock preferences for bioenergy; multi-level governance, and impacts of governance on bioenergy production and trade; awareness about bioenergy; and attributes driving opinions about bioenergy. According to Radics et al.,[65] most studies are carried out either an online survey or interviews to assess the view of stakeholders. Only 4% of the studies combined both communication methods.

This study is accomplished as part of the IEA Bioenergy project "*Measuring, governing and gaining support for sustainable bioenergy supply chains*". Two of the project objectives are to a) understand the position and underlying motivations of diverse stakeholders related to their role in bioenergy development; b) inform dialogue and discussion to avoid misconceptions as well as provide neutral and comprehensive knowledge on the bioenergy sector. To achieve this objective, three regional case studies are conducted to assess the views and position of stakeholders relevant for three bioenergy value chains at regional and national levels: biogas in German,[126] woody biomass for energy and agricultural biomass for biofuels in Canada,[127] and the US.[128] These studies were co-funded by various national programs and, therefore also used slightly different approaches. However, there is a lack of studies that analyse the position and vision of stakeholders towards bioenergy (i) at a global level, and which also (ii) deploy multiple methods at the same time to assess, verify, and consolidate the results. Such a comprehensive study is important to provide a clearer picture of how bioenergy is viewed, also from a global perspective. As the international trade of bioenergy products is increasing, it become more critical to have information on position of stakeholder groups from local to global levels, which can guide the bioenergy industry to develop sustainably. This is a precondition to the legitimacy of the bioenergy-related activities.

To fulfil the objectives, the stakeholders are divided into eight different stakeholder groups, and data are collected through various consultation channels including an online questionnaire, roundtable dialogues, and in-depth interviews. The roundtable dialogues allow stakeholders to discuss and validate results of the online questionnaire and the interviews, thus elucidating the position and vision expressed by supranational stakeholders. The study also gives an improved understanding of the position and underlying motivations of diverse stakeholders relative to their role in bioenergy. Finally, the study indicates how the position of stakeholders and their institutions may affect bioenergy policies and the sector development in the future.

3.2 METHODOLOGY

A variety of methodologies has been developed and applied to identify, map, and understand position and vision of stakeholder groups as well as their influence on the bioenergy sector. For example, an applicable framework for the assessment, design, implementation, and communication of quality stakeholder engagement was developed to identify stakeholder groups, their position and perception to understand their expectations about governance, policies, and strategies concerning bioenergy.[129] Other frameworks were developed for specific case studies with the aim to analyse the viewpoints and social acceptance of stakeholders of biomass projects.[64,69,130] Taking into account various approaches used in previous studies including their shortcomings, a method was developed for this study, which focused on classification of stakeholder groups and assessment of the position of stakeholders by using a number of communication channels. The method included six steps (Figure 3.1).

The first step involved the identification and classification of eight stakeholder groups and screening of their roles. Stakeholder groups were classified as either being directly involved in the bioenergy supply chains or not; the former included *biomass producers*, *biomass users for bioenergy*, and *biomass users for other purposes* (such as stakeholders of the biomaterials and biochemical industries). Outside of the supply chains, stakeholder groups included the *general public* (consumers, local communities), *academia and consulting* (research institutions, consultancies), *non-governmental organisations* (*NGO*s), and *policy makers*. There was also a supranational stakeholder group, which is considered active and interested in bioenergy on an international level, rather than on a specific case level. They show an understanding and awareness of bioenergy.

The second step was to define the different roles of the stakeholder groups. *Biomass producers* are actors who supply feedstocks, and are involved in the cultivation, harvesting and collection, storage, and logistics of biomass. *Biomass users for bioenergy* and for other purposes are stakeholders involved in the bioeconomy sectors or in the supply chains of biomass for various purposes: logistics, pre-treatment, and conversion of feedstocks to products of the bioeconomy. The other stakeholders outside the supply chains have some interests in bioenergy, and bear some levels of influence on bioenergy development. The supranational stakeholders are the stakeholders with more influence on bioenergy development. As this paper focuses on the potential role of bioenergy on a global level in the medium- to long term, most of consulted supranational stakeholders have a clear vision on the role of bioenergy in the long-term timeframe. However, it was not always evident what the main perception and drivers for these vision are. Therefore, communication with selected supranational stakeholders was particularly important to analyse how they vision the bioenergy sector, and to explore how bioenergy could move forward sustainably.

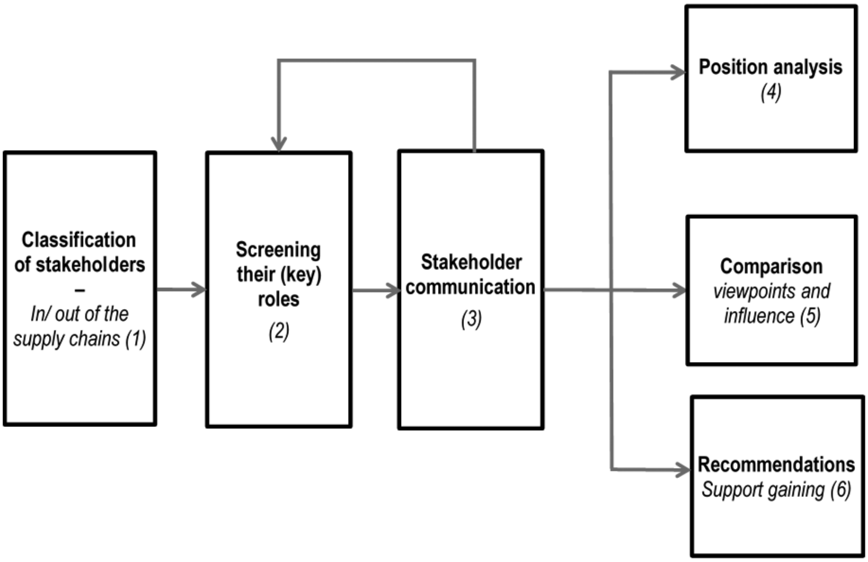

Figure 3.1. Method to identify position, perception and vision of stakeholders on bioenergy

The third step was to communicate with stakeholders via questionnaires, interviews, and dialogues to understand their viewpoints and influence on the bioenergy sector. We defined perception is the ability of stakeholders to understand an issue, and position of stakeholders as their ability to perceive and give opinions about that issue. In this study, perception was briefly investigated based on their responses to general information of the bioenergy sector, whilst position was measured as the level to which a stakeholder agrees with a statement from strong disagreement to strong agreement level. Vision was defined as the ability to think and plan for the future based on the expertise and experience. Once stakeholders provided statements how they view bioenergy in the short, medium, and long term, their vision was observed. The communication approaches (see Table 3.1) are explained in sections 3.2.1, 3.2.2 and 3.2.3. For the roundtable dialogues with selected stakeholders and interviews with the supranational stakeholders, the communication outcomes were documented and sent to those stakeholders for their review and approval. The communication results published in this paper have been approved by all stakeholders.

Table 3.1. Contributions from different communication approaches

Issues addressed	Online survey	Roundtable Dialogues	Interview
Position of stakeholders	X	X	X
Perception towards bioenergy	X	X	X
Vision on bioenergy		X (partly)	X
Influence on bioenergy development		X (partly)	X

The fourth step was to capture information about the position, awareness, and interest of the stakeholders inside and outside the bioenergy supply chains, then interpreted why certain stakeholders have more influence than others (and in what contexts).

The fifth step was to compare the viewpoints and vision of the stakeholder groups of different bioenergy value chains and to the bioenergy sector. This step also aimed to understand, and predict the level of interests and influence of stakeholders on bioenergy development, in order to provide a future recommendations following the approach of Reed et al. (2009).[131] The figure of interest and influence was drawn to map stakeholder interest and influence with inputs from the dialogues and interviews with supranational stakeholders.

The final step provided discussion and proposed recommendations for how the bio-energy sector can gain (further) support from stakeholders for sustainable bioenergy development and value chain management.

3.2.1 Online survey

The questionnaire was developed with the aim to receive a brief poll of perception and vision of seven stakeholder groups towards the bioenergy sector. The questionnaire covered various aspects of bioenergy development, established through discussion with bioenergy consultants and scientists who participated in this project. The aspects included awareness of the stakeholders of bioenergy development; conditions under which to support bioenergy; suitable feedstocks to be used for bioenergy production;

drivers, barriers and challenges for bioenergy development; and how to gain (further support) for bioenergy sustainability. The questionnaire was reviewed and approved by the project Advisory Board. There were several questions which included five levels of agreement: strong agreement; agreement; neutral viewpoint; disagreement and strong disagreement (stakeholders could also provide their own opinions). The questionnaire is provided in the S.I.3.

The questionnaire was disseminated via the project participants to their networks, to several websites of IEA Bioenergy and its members. In addition, the questionnaire was also announced at a number of events and conferences in which project members participated. Once the questionnaire was completed, an analysis of position, viewpoints, and vision of the stakeholder groups was carried out. The analysis included the average ranking of agreement and acceptance levels by the stakeholder groups. Also, the standard deviation of the answers of the respondents was quantified. A low standard deviation indicates that answers tend to be close to the average ranking, while a high standard deviation indicates that responses are spread out over a wider range of values.

3.2.2 Roundtable dialogues with invited stakeholders

The roundtable dialogues were designed to consult a number of stakeholders having interests and expertise on bioenergy to receive feedback on the questionnaire results, and to reflect their vision for future pathways and strategies for sustainable bioenergy development. The stakeholders mostly had a position that may have influence to, and clear vision on bioenergy development. They jointly answered four questions:

- Which results of the online questionnaire are in line with their expectations?
- Which results of the online questionnaire are unanticipated? Are their own areas of disagreement with other stakeholders the same as those emerging from the questionnaire?
- Are there other main areas of disagreement?
- What are possible areas of agreement (or where agreement may be achieved fairly easily)?

3.2.3 Interviews with supranational stakeholders

A number of organisations that relate to or have influence on bioenergy development were identified. This investigation of relevant organisations was also completed through communication with, or recommendations from other stakeholder groups. Supranational stakeholders representing selected organisations approached included experts and policy makers from the European Commission and Parliament; United Nations (UN) organisations; World Bank and regional development banks; international NGOs (e.g. Greenpeace, IUCN, WWF); bio-based industry (e.g. DSM, Unilever), and their EU and global associations (e.g. Bioenergy EUROPE, WBA); fossil fuels-based industries (e.g. BP, Shell); EU and international forest owner associations, selected forest-related industries; biomass sustainability certification bodies (e.g. RSB, ISCC), including forest certification bodies (for example FSC, PEFC); international agricultural businesses and land owner associations.

The supranational stakeholders were identified based on their published information and relevant works linked directly or indirectly to the bioenergy supply chains. Their communication, presentations and publications on biomass and bioenergy issues were also reviewed. The invitations were delivered to the supranational stakeholders and once agreed to participate in this study, they firstly answered the questionnaire then responded to eight questions via an interview. The interviews were designed to identify the vision and involvements of their institutions in bioenergy, or their influence on the development of the bioenergy sector. The additional questions include:

a. Public involvements in bioenergy projects: What would be the recommendations and to what level of involvements?
b. Involvement of organisation of supranational stakeholders in bioenergy: what projects and or programme have done related to biofuels/ bioenergy sustainability?
c. Bioenergy end-use: what are the most important end uses of bioenergy?
d. Perspectives: what are the perspectives on the bioenergy market, trade, willingness to pay?
e. Sector policies: what would be the most important policies for bioenergy development?
f. Recommendations: Under what conditions could the bioenergy actors gain (further) supports from external stakeholder groups?

g. EU policies on bioenergy: The EU is a good example of bioenergy development and sustainability compliance. The EU has ambitious targets for bioenergy including biofuels, heat and electricity sectors. How can the targets be met?
h. How do you view the sector in the short- medium and long terms?

Their responses to the questionnaire were reviewed and discussed in the interviews to ensure clear answers and explanations of all the identified issues. Once the questionnaire and interviews were completed, an assessment of the position, viewpoints, and vision of the supranational stakeholders was carried out. This assessment investigated how these stakeholders viewed the roles of various bioenergy supply chains. Also, the assessment revealed whether the current actions of the supranational stakeholders match their long-term vision. In case their answers were inconsistent, further communication and investigation was also carried out for detailed clarifications. The assessment aimed to identify to what extent there was a coherent vision among different supranational stakeholders. The assessment aimed to answer whether the supranational stakeholders exerted an influence on the bioenergy supply chains and on development of the bioenergy sector in the medium and long term.

3.3 RESULTS

3.3.1 Online survey

Stakeholder participation

The online questionnaire received contributions from more than 200 participants, with 199 of these being complete for further data processing. The contributions came from the seven defined stakeholder groups including contributions of the supranational stakeholders (see Figure 3.2).

The questionnaire received most contributions from the academia and consulting group (35%), with the second largest group being NGOs (17%), policy makers (15%), and biomass users for energy (12%). Participation rates from other groups were lower than 6-8%. This constituted a fair number of stakeholder groups, and it is thus expected that the results reflect well the interests and involvement of stakeholder groups in the bioenergy sector.

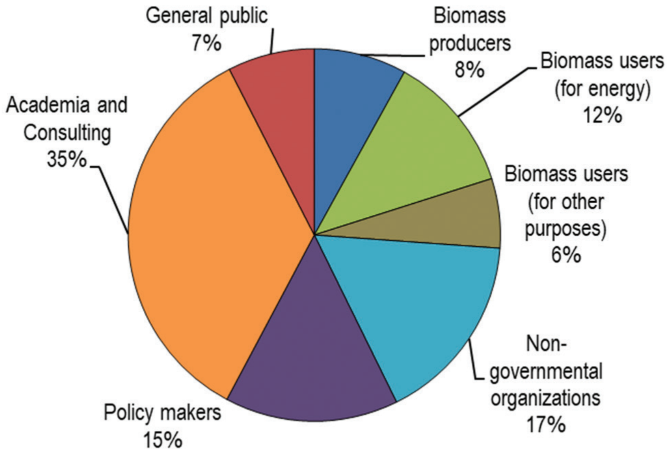

Figure 3.2. Relative distribution participants of the seven stakeholder groups in the online questionnaire, with contributions of the supranational stakeholders among the answers as belonging to some of the other groups.

Awareness

In general, the respondents declared that they were aware of bioenergy development, and had a rather positive view of the sector, with the most positive views from the biomass users for energy, NGOs, and academia and consulting groups. Together with policy makers, these three groups showed the highest level of self-expressed awareness of activities of the bioenergy sector. The biomass users for bioenergy expressed the highest level of awareness of bioenergy development. The respondents generally indicated that the general public is too little aware of bioenergy, and this group should be more informed and involved in the development of the sector. In designing bioenergy policy, the respondents did not agree that the general public should have more influence than scientific evidence. The general public themselves did not consider their voice more important than scientific facts (see Figure 3.3).

The standard deviation showed that within the stakeholder groups, the answers were varying compared with the average level of agreement.

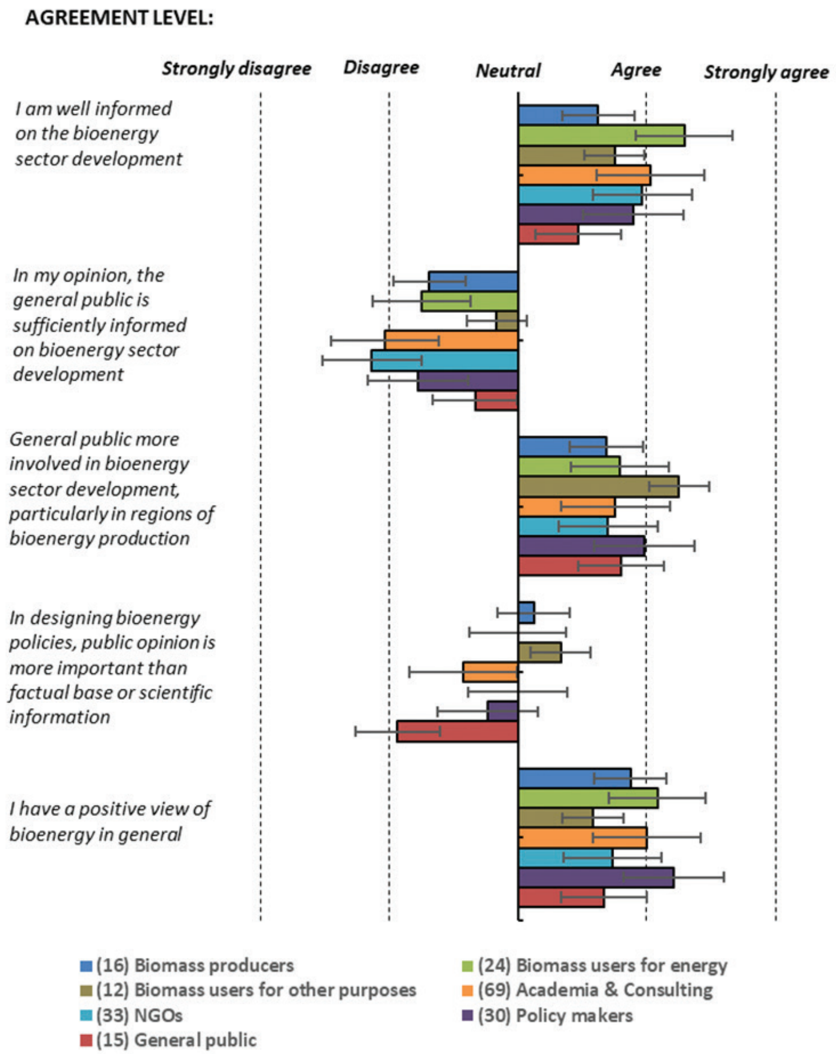

Figure 3.3. Stakeholders rating of their own awareness and general view on bioenergy development. Bars show that answers varied most among stakeholders within the groups Biomass Users for Energy, Acamdemia & Consulting, and NGOs.

Feedstocks used for bioenergy

The results concerning feedstocks used for bioenergy production (see Figure 3.4) showed a high level of acceptance (average 70%) for the use of agricultural residues (harvesting and processing crop residues), energy crops cultivated on marginal or degraded land, as well as forestry residues (from conventional harvest operations, processing, urban wood and low value wood). This acceptance originated mostly from the biomass producers, biomass users for energy, NGOs, policy makers, academia and consulting groups. Many stakeholders indicated their choices for those agricultural and forest feedstocks for the reason that these biomass feedstocks bear a low sustainability risk if used for bioenergy production. The biomass users (for other purposes than bioenergy) indicated a low acceptance of various feedstock types used for bioenergy production.

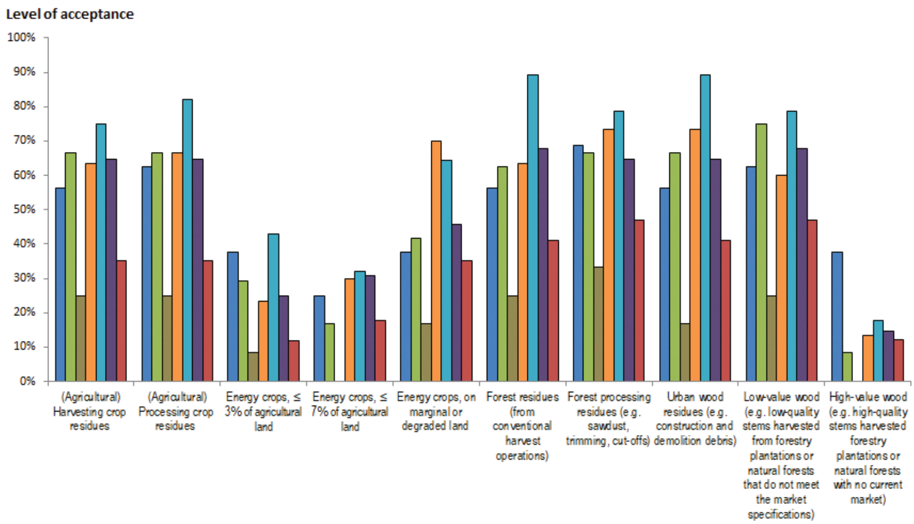

Figure 3.4. Preferences of feedstock types used for bioenergy production

Most energy crops grown on a certain percentage (e.g. ≤ 7%, ≤ 3% of the land area), or the use of high-value wood harvested from plantations and natural forests (even those with no current market) for bioenergy received little support from any stakeholder group.

Information about the bioenergy sector

The stakeholders were asked what sources of information they consulted about bioenergy, and what sources of information they trusted most. Results show that internet sources, social media, television, local events, and traditional newspapers provided a high percentage of the information (more than 70% stated these are their main sources, see Figure 3.5). Meanwhile, publications from academia and consulting - although they did not contribute significantly to the popular dissemination of information - were considered the most credible information sources. In addition, some stakeholders expressed that they gained knowledge about bioenergy through their own experience and network.

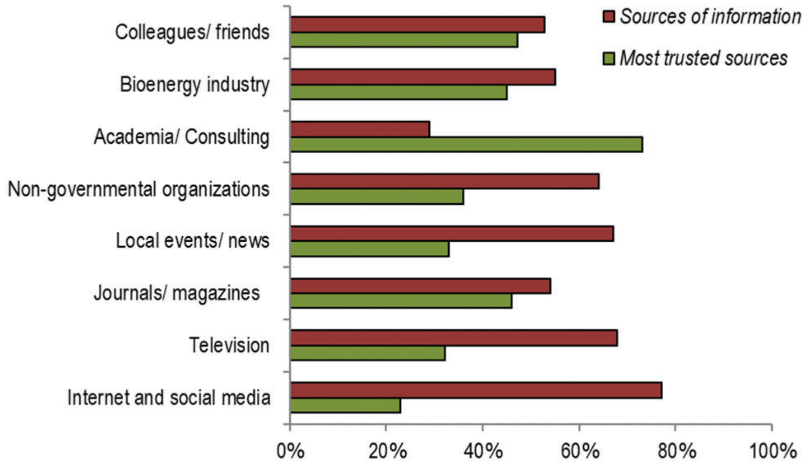

Figure 3.5. The types of consulted sources and most trusted information sources about the bioenergy sector

Support or disapproval of bioenergy

The stakeholders were asked whether they support bioenergy development based on 6 stated arguments: increase of energy supply security, local job creation and economic development, reduction of air and water pollution, increase of reuse and recycling of materials, improvement of soil and forest management, and conservation of biodiversity and ecosystem services. Most of the stakeholder groups agreed that these aspects were all important (see Figure 3.6). The highest agreement came from the academic and consulting group.

The biomass users for other purposes disagreed with the aspects a) increase of energy supply security, and b) local job creation and economic development. In addition, they provided additional comments that other sectors such as pulp and paper, and construction traditionally create more jobs and stimulate more economic development than the bioenergy sector.

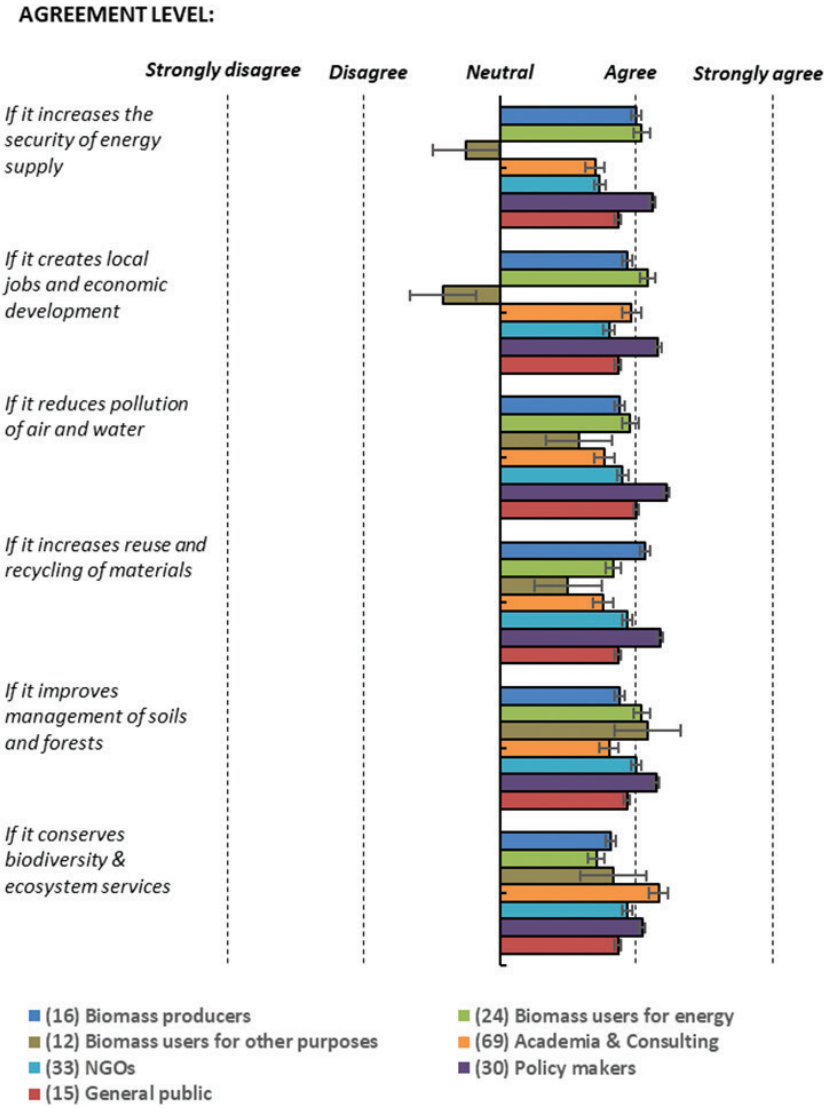

Figure 3.6. Rating of reasons for support of bioenergy development. Bars show a low variation of answers within each group, with highest varying answer for the group Biomass users for other purposes.

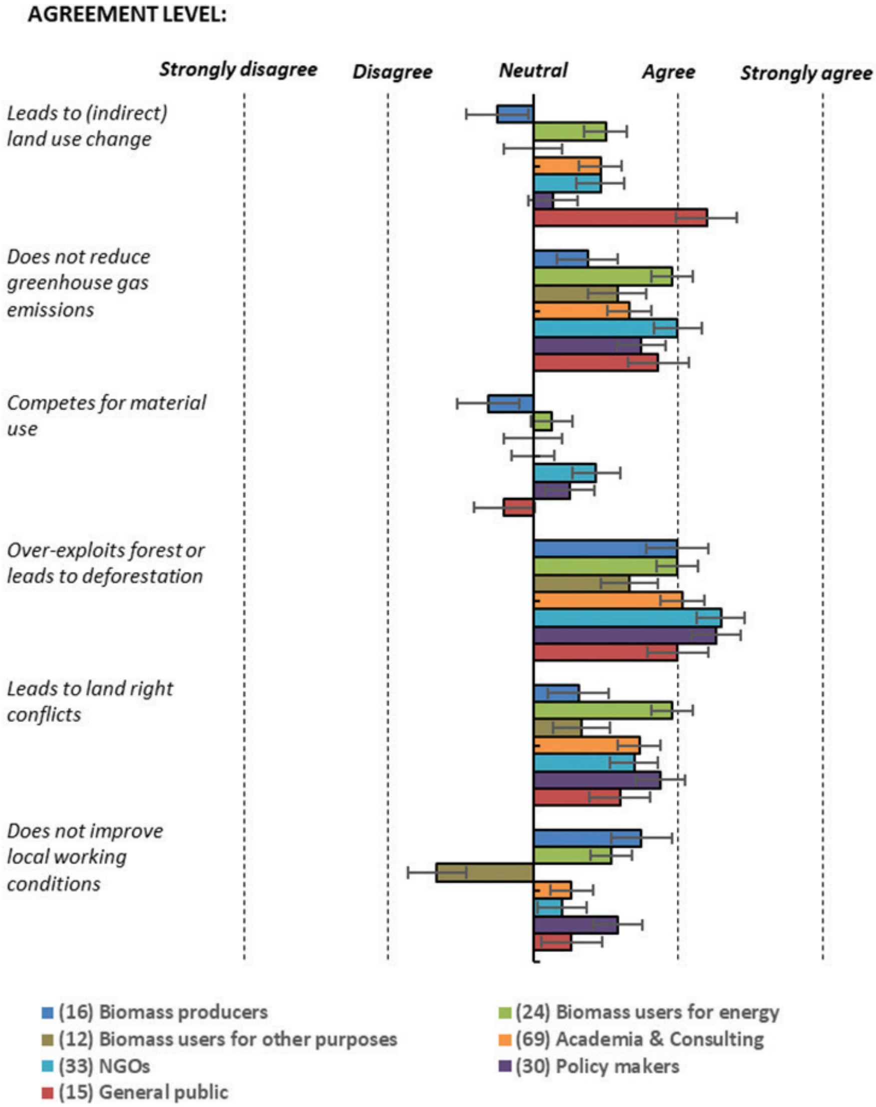

Figure 3.7. Rating of reasons to disapprove of bioenergy development. Bars show the same level of variation of the answers within all groups.

The stakeholders were also asked if they would disapprove of further bioenergy development if it leads to a number of negative impacts. All stakeholders agreed on three issues: over-exploitation of forest or deforestation, land rights conflicts, and especially negligible or no reduction of GHG emissions as reasons to not support bioenergy development (see Figure 3.7). Furthermore, all stakeholder groups took a neutral position on competition with material uses.

For other impacts, the results were more varied. Potential indirect land use change (iLUC) was considered a serious reason by the general public to disapprove bioenergy, whereas all other stakeholder groups were close to a neutral view on this issue. Regarding the lack of improvement of local working conditions, the biomass users for other purposes did not consider this an issue, whereas all other groups saw this as a minor reason to disapprove of bioenergy development.

Barriers and challenges for the bioenergy sector

Most of the stakeholder groups considered lack of economic stimulation and market incentives as well as unresolved sustainability issues (resulting in policy and market uncertainty) as the two main barriers to bioenergy development. The lack of scientific information for better informing policy makers and the general public was also viewed as a barrier, but deemed less important than the two aforementioned aspects (see Figure 3.8).

A key challenge for the bioenergy sector, agreed upon by most stakeholders, is the lack of general social acceptance. Undesired environmental impacts that cannot be avoided or no contribution to economic growth were not considered serious issues according to all stakeholder groups (see Figure 3.9).

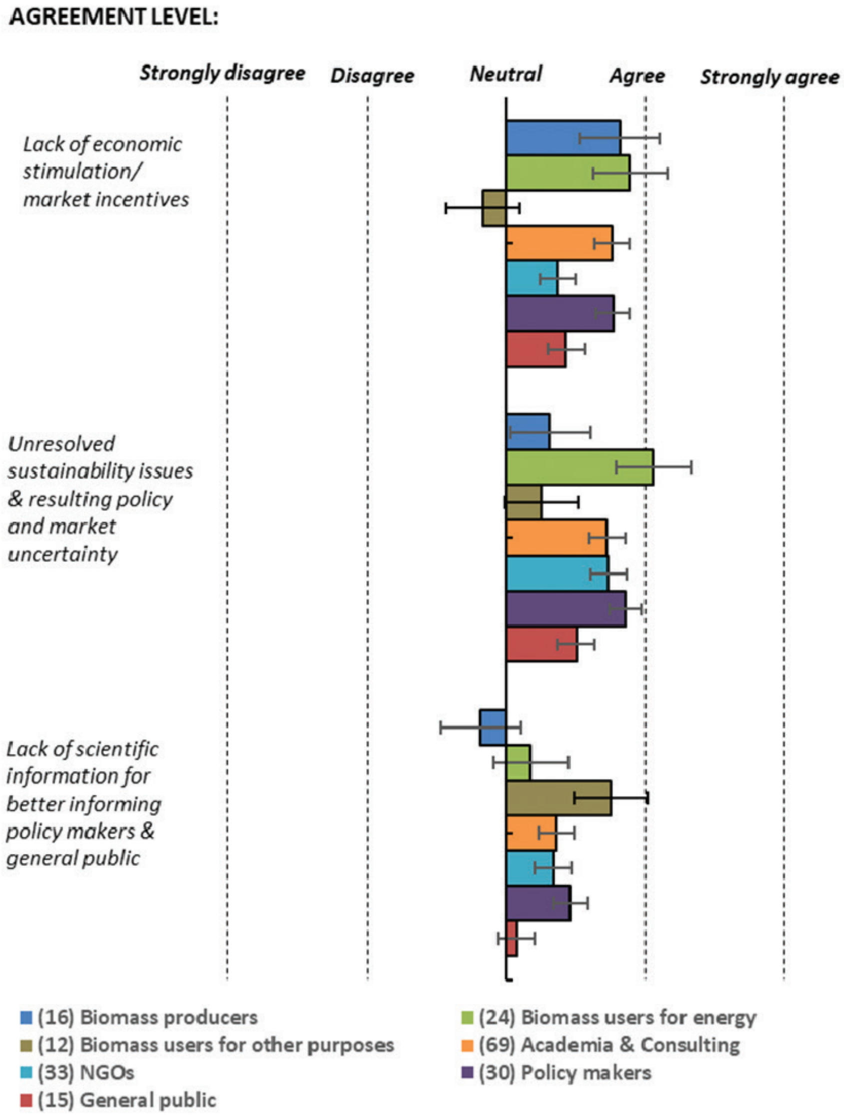

Figure 3.8. Rating of barriers to bioenergy development. Bars show answers varied most within the groups Biomass producers, Biomass users for energy, and Biomass users for other purposes.

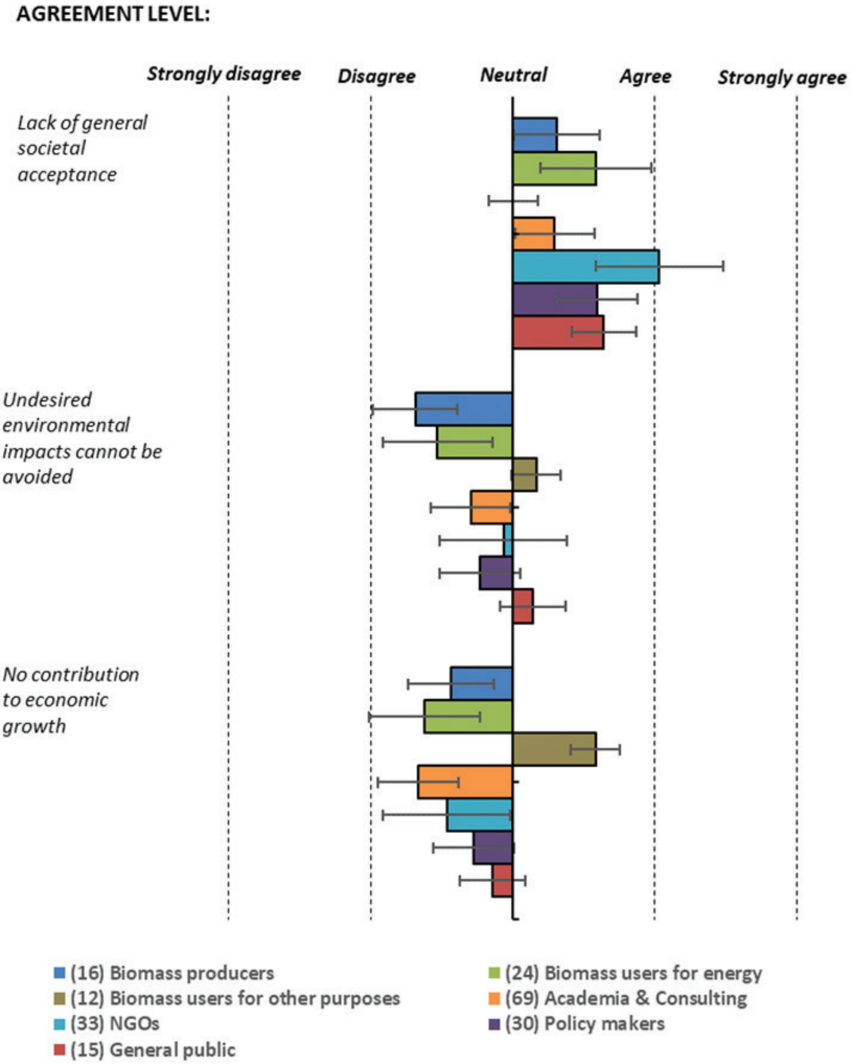

Figure 3.9. Rating of challenges for bioenergy development Drivers and barriers to bioenergy development

The stakeholder groups were also asked if they agreed with the five presented drivers of bioenergy development: reduction of GHG emissions, reduction of environmental impacts, creation of profitable businesses based on biomass, development of a circular economy, energy security and security of energy supply. In principle, all stakeholder groups agreed that these factors are drivers but indicated their highest agreement with the reduction of GHG emissions (see Figure 3.10).

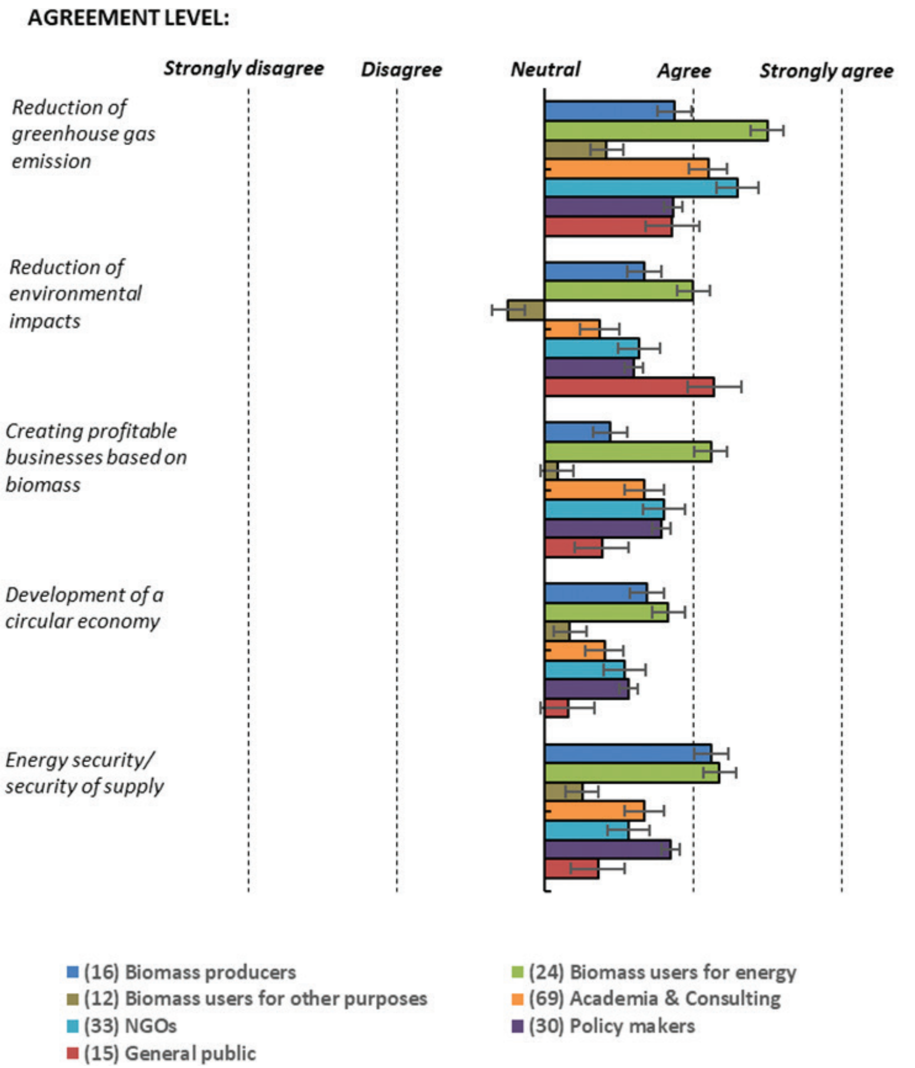

Figure 3.10. Rating of important drivers of bioenergy development. Bars show a low variation of answers among all groups.

The stakeholder groups were also asked how the bioenergy sector could gain or enhance support. Most stakeholders agreed that one of the most promising ways is the introduction of binding sustainability requirements for all types of biomass feedstocks, whether used for bioenergy but (remarkably) or other end-uses. Especially the bioenergy end-users showed a highest agreement. Another well-supported position was that to increasingly base bioenergy policies on scientific information. The stakeholders did not completely consider that current certification schemes are transparent and effective, indicating that further improvements are needed (see Figure 3.11).

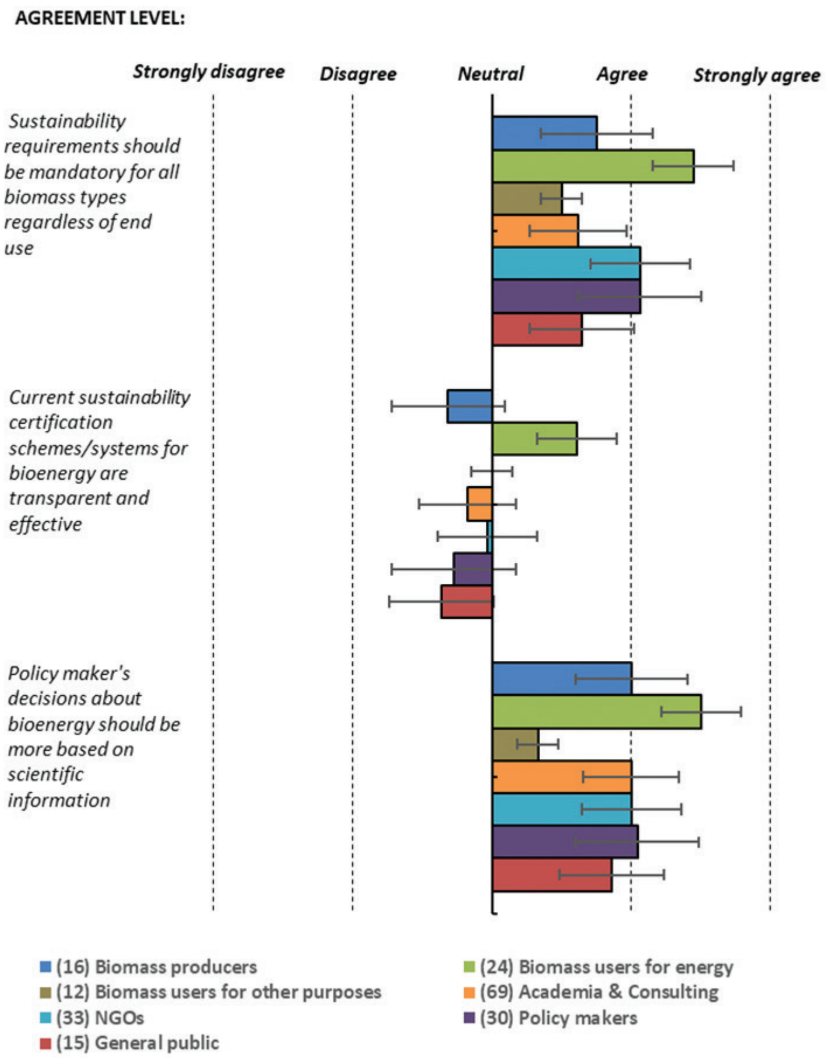

Figure 3.11. Rating of conditions to gain (further) support for bioenergy development. Bars show highly varying answers among stakeholders in most groups.

3.3.2 Roundtable dialogues with invited stakeholders

The questionnaire results were discussed in two roundtable dialogues. The two events engaged relevant stakeholders. A total of fifteen stakeholders participated, representing NGOs (Danish Society for Nature Conservation - DN, World Wide Fund for Nature - WWF Europe, Global Biomass Partnership - GBEP, Confederation of European Forest Owners - CEFP), two independent consultants, biomass users for energy - Hofor, Enviva, Drax, a certification scheme (Roundtable on Sustainable Biomaterials - RSB), industry associations (Danish Energy, Brazilian Sugarcane Industry Association - Unica), an union (United Federation of Danish Workers - 3F), and intergovernmental organisations (Food and Agriculture Organisation of the United Nations FAO), International Renewable Energy Agency - IRENA).

Anticipated results in line with participants' experience

Overall, more than half of the participants stated that the positive view of the stakeholder groups was in line with their experience, and they commented that bioenergy receiving the support of many stakeholder groups was a good signal for the bioenergy sector. They agreed with most of the questionnaire respondents that GHG emission reduction was the main driver of bioenergy development. Also the view that the general public was not aware of bioenergy activities with more efforts needed to be made to inform the general public was confirmed. The concerns of negative impacts of bioenergy expressed by the general public, and a lack of social acceptance of bioenergy were also recognised by the dialogue participants.

The participants confirmed that they understood why the biomass users for other purposes often gave answers differently than other groups, as this is consistent with the interest of this group. The participants commented that this group uses biomass feedstocks that are similar to those used for bioenergy production, and that feedstock competition was likely an aspect that made this group reluctantly to support the development of the bioenergy sector. Most participants commented that the bioenergy sector should take the concerns of this group into account.

The participants also supported the view expressed in the questionnaire concerning drivers, barriers, and challenges for bioenergy development, showing that social and economic aspects should be taken more into consideration as sustainability dimensions. The participants noted that sustainable forest management (SFM) and some social and economic aspects have been implemented in some EU Member States. However, clear definitions for these criteria need to be agreed upon at a global level.

Unanticipated results in line with experience of participants

Half of the workshop participants commented that positive view of the NGOs of bioenergy was surprising, and they recommended contacting additional environmental

NGOs to receive more opinions. This was consequently done. It did not change general impression as presented in Section 3.1, even though this group were somewhat less positive compared with the view presented in these events. This may be because many participating NGOs only not represent environmental groups, but also include bioenergy industry associations, forest and farmer associations, who generally support bioenergy development.

Some participants stated the social and economic benefits of the bioenergy sector should be highlighted as a driver. Regarding information sharing, the participants indicated their disagreement that information from the bioenergy sector is not especially trusted, while that from the academia and consulting is more trusted. Other participants noted that there was a lack of understanding about bioenergy, and the contributions of bioenergy to the bioeconomy. The participants were negatively surprised that mandatory sustainability requirements for bioenergy as well as bioenergy policy based on scientific information did not receive (even) higher levels of support than shown in Figure 3.11. They agreed, however that improvements are still needed for the certification schemes that are already deemed transparent and effective. According to them, the certification schemes need to be more inclusive, and involving more comprehensive measures of sustainability indicators for bioenergy.

Regarding feedstock use, several participants expressed concerns regarding the low support for energy crops, except on marginal and degraded lands, as these feedstocks are important for expanding bioenergy. They found that bioenergy crops would be acceptable in addition to other biomass feedstocks, if sustainability compliance were established and compliance demonstrated. They also highlighted that with improved yields for food crops, there would be more land available for bioenergy crops, and that could have an important role in decarbonising the transport sector. In addition, information sharing and generally sustainable biomass were emphasised as important to gain or enhance support for bioenergy. They also emphasised that market mechanism are important for creating a fair distribution of biomass feedstocks for all relevant sectors.

Other areas of disagreement with the questionnaire results

The participants also identified the lack of scientific information for better informing policy makers and the general public, as a barrier to bioenergy development, highlighting that such information needs to be carefully presented to external stakeholders. It was also seen as a challenge that scientific papers present conflicting results on bioenergy. This was considered to confuse stakeholders, particularly those actors who have influence on bioenergy development. Other participants mentioned that bioenergy debates would be needed to identify which results are credible. Also, information was seen as needed on how bioenergy can make contributions to economic growth.

Regarding sustainability safeguards for bioenergy, many stakeholders agreed that implementing sustainability requirements for bioenergy at a global level is inappropriate; sustainability verification should be carried out at a local scale to assure accurate outcomes, in particular in relation to sustainable land management.

Other areas of agreement with the questionnaire results

Some participants believed that bioenergy has an important role in the future energy system, but also that the sector would need to take the Paris Climate Agreement into account. In order to keep global climate change impacts at 1.5°C warming above the pre-industrial level, GHG emissions need to be reduced dramatically through afforestation and reforestation. They also considered that a percentage of forest biomass could be made available for bioenergy, if necessary to agree which forest types that are suitable for sustainable biomass harvesting, particularly for tropical forests and rainforests. They also expressed the importance of avoiding forest overexploitation, for example by implementation of low LUC and iLUC measures. The general public should also receive information on land use effects of biomass cultivation and harvesting, including the positive as well as negative effects of bioenergy, if evidence of such effects can be provided. They saw that energy crops as well as forest waste and residues are sensitive topics in terms of gaining support, and considered that such support might depend on the expected usage and volumes. They suggested as a solution that agreements be reached on feedstock use, biomass cascading, and biomass applications in various sectors.

Many participants emphasized that vision on bioenergy should be clear and more explicit to guide the sector to a proper development. They expressed that policies missing a long-term perspective are barriers to investment. Transparency and communication with other related sectors and external stakeholders were deemed helpful for bioenergy to strengthen its position, as was enhanced collaborations between the bioenergy sector and the scientific community for communicating their scientific results to NGOs and policy makers. They said that bioenergy policies should then be based on facts, but also that information delivered to policy makers must comprehensible for this non-expert group. Similarly, information about bioenergy needs to be adequately simple for the general public to understand the development, and its benefits and impacts.

Several participants noted that the social components, such as income and job creation, and local development should be included as voluntary sustainability indicators in the sourcing regions of biomass feedstocks as demonstrating compliance is costly, time consuming, and do not involve critical risks. If economic operators comply with such voluntary requirements, they may receive premium for bioenergy production (in some regions), and or social acceptance, increase market share (for sustainable bioenergy). These components are particularly important in the developing countries where there is often a lack of stringent regulation or enforcement, or lack of compliance with local rights and laws. Social, economic and environmental dimensions and compliance with laws or guidelines were considered helpful, for the bioenergy sector to be supported by other stakeholder groups.

3.3.3 Interviews with supranational stakeholders

Out of thirty invitations sent, eleven supranational stakeholders agreed to answer the questions. Several supranational stakeholders did not respond to the interview invitation including a number of US policy makers, fossil-fuel based industry, one development bank, and international economics organisations.

The following supranational stakeholders clearly stated that the answers given represented the views of their organisation: DSM (bio-based/ chemical industry), Transport & Environment (NGO), Greenpeace (NGO), RSB (certification scheme), RVO (Policy department, Netherlands Enterprise Agency), Bioenergy Europe (bioenergy industry organisation), and UNEP (UN organisation). Other supranational stakeholders, although representing institutions with a significant influence on bioenergy development, presented their answers as personal opinions. They explained that their organisation did not have broad activities covering all aspects identified in the questionnaire and in the interview questions. Those stakeholders included representatives from Hofor (bioenergy industry), Rainforest Alliance (NGO), World Bank (development bank), and FAO (intergovernmental organisation).

The opinions and answers of the supranational stakeholders to the eight questions identified in Section 2.3 are presented below. Most of the institutions to which the supranational stakeholders (or the supranational stakeholders themselves) have published reports and position papers on bioenergy.[95,132–136] Many supranational stakeholders have also participated in dialogues, discussion and projects on bioenergy, and provided references to further support their opinions and perception.[137,138] In the interviews, they elaborated further on their vision for bioenergy.

Public involvements in bioenergy projects

The questionnaire results showed that most of the supranational stakeholders agreed strongly that the general public is not sufficiently aware of bioenergy development, and the general public should be more involved in bioenergy project implementation. In the interviews, they stated that public concerns and debates need to be recognised, for example when considering bioenergy effects combating climate change, food security, sustainable forest management; or impacts on human rights and land rights.

Three supranational stakeholders noted that raising awareness through bioenergy campaigns should be prioritised, with the general public involved in provisioning of local information and report environmental impacts of bioenergy projects. For sustainable value chains, local communities could contribute to feedstock sourcing and supply, and sustainability compliance. It was also suggested that these communities could also be consulted for public policy development, even if a potential risk of bad decision making as seen as an aspect that also needed to be considered.

Most supranational stakeholders recognised that bioenergy has various forms produced by various technologies delivering different end-uses, thus making it difficult to derive a clear picture of what bioenergy truly is. According to them, it is important to develop communication strategies to inform the public of actual bioenergy activities and future plans.

Awareness and participation on bioenergy sustainability

Eight of the eleven supranational stakeholders indicated a clear vision on bioenergy, and the majority stated that they have knowledge on bioenergy markets, policies, and sustainability criteria and certification. Many had been involved in developing and discussing legislation for bioenergy in Europe and its Member States, as well as in implementing and managing sustainability compliance for bioenergy. They were familiar with, and involved in projects of feedstock mobilisation with the participation of companies, landowners, forest communities, and partner organizations.

However, the role of bioenergy and its contributions to climate change mitigation was still in question by three supranational stakeholders. Those stakeholders commented that bioenergy needs to be sustainable if the sector should continue to grow. In addition, some supranational stakeholders had concerns that, the actual GHG emission reduction under certain conditions was not as high as initially assumed. They had a positive impression of that the EU revised Renewable Energy Directive 2018 (RED II) defining binding sustainability criteria for the whole bioenergy sector to enhance sustainability compliance. The RED II was seen by some stakeholders to have weak requirements for GHG emission reduction. However they believed the RED II will be helpful to harmonise sustainability criteria among Member States and will respond to the sustainability concerns of the general public. They concluded that similar sustainability criteria should be adopted at the global level.

Prioritisation of bioenergy end uses

All the supranational stakeholders mentioned that modern bioenergy is particularly important in the transport sector. Eight supranational stakeholders also considered end-uses in the heat and electricity sectors to be important. Three supranational stakeholders emphasised the role of bioenergy in aviation, and for biomaterials and maritime uses. However, most of them also highlighted that the end-uses should rely on regional policies, and emphasised a consideration of environmental and climate protection, and possible environmental costs. Four participants recommended further considering the cascading principle, using feedstocks of high quality for biofuel or biomaterial production, whilst waste and residues should be processed for heat and electricity.

Six supranational stakeholders mentioned that local contexts of bioenergy production play a role for its development. Biofuels are becoming popular in the US, South America, and the EU, but biofuels consumption is small outside of these regions. For further development, it was seen as important to carefully assess sustainability, particularly land-related issues.

Perspectives on bioenergy market, trade and willingness to pay

Seven of the eleven supranational stakeholders stated that sustainability certification can help in establishing bioenergy trade. The sustainability certification can also increase willingness to pay for bioenergy, even if it might be difficult to document in developing countries due to a lack of effective governance and institutional frameworks. They saw it as a barrier for trading, but also saw as an opportunity to mobilize more scattered feedstocks in other regions. Development of sustainable value chains would create extended markets for bioenergy, ultimately with customers willing to pay for sustainable bioenergy uses.

Four supranational stakeholders also emphasised that market price, market transparency, and cost effectiveness play important roles in bioenergy sector development. Bioenergy markets in many countries are mainly policy driven, with bioenergy depending on subsidies, carbon prices, etc. Other renewable energies (solar panels, wind power) are becoming cheaper, and thus more competitive and would likely gain markets. But four others stated that the bioenergy sector is gradually moving forward thanks to its contributions to secure energy supplies and stabilisation of electricity grids with increasing but intermittent shares of solar and wind power.

Important policies for the sector development

Seven supranational stakeholders emphasised that concrete policies for bioenergy were not yet on the political agenda in many countries. Policies should be well designed and implemented to support sustainable growth. Also, policies should help incentivise bioenergy to successfully compete in markets with fossil fuels. The following points were considered important policies:

› Sustainable sourcing and fair competition: six supranational stakeholders highlighted these issues as important to address in policies for bioenergy. The use of biomass feedstocks should be fair, and avoids competition with other bioeconomy sectors using the same feedstocks . Policies guiding the bioenergy sector to develop sustainably and enhanced collaborations with related sectors are considered key for sustainable long-term development.

- Carbon accounting and energy price: six supranational stakeholders indicated that sustainable bioenergy produced from biomass in principle emits much lower levels of GHGs than fossil fuels. A joint climate and energy framework as well as energy policies taking into account environmental and social costs in the final energy prices should be developed. This will ensure a fairer competition among energy carriers, and it would be important for the sector to grow further and receive further political support.

- Sustainability requirements: according to five supranational stakeholders, comprehensive sustainability criteria are needed, both for the production of the biomass and conversion to end uses. The EU binding sustainability criteria are a good example to demonstrate how sustainability compliance can be extended to other regions of the world, through sustainability certification of voluntary schemes, such as the FSC or the ISCC. Concrete definition of sustainability criteria, and sustainability monitoring for bioenergy need to be established for global issues, for example, iLUC. However, consensus on measures at a global level has not been reached. The supranational stakeholders noted that ensuring no land competition for food could help gain more support for bioenergy. In addition, the SFM criteria needs to be more broadly applied so that biomass collection does not have adverse impacts on biodiversity and ecosystem conservation.

- Decarbonisation and aviation: five supranational stakeholders argued that policies on decarbonizing the transport sector would be very important. Also, a global Emissions Trading System (ETS) and related efficiency requirements would stimulate the bioenergy sector to develop further. Four supranational stakeholders saw potentials for bioenergy in aviation to be further expanded, and thus policies for aviation could be a significant driver.

Recommendations for the bioenergy sector to gain support

The recommendations from the supranational stakeholders are as below:

- Sustainability compliance and transparency: for six supranational stakeholders, these aspects are important for the bioenergy sector to receive support. Proper implementation of certification would ultimately leads to more confidence in bioenergy investment. Providing information for sustainability reporting, and verification of bioenergy development should therefore be on the agenda of bioenergy stakeholders.

- Bioeconomy: three supranational stakeholders mentioned that a level playing field for all bio-based sectors, including bioenergy, is important.

- Information and communication: According to six supranational stakeholders, an open attitude towards sustainability is the key to opening the door to the bioenergy future, involving several sectors in finding mutual solutions (e.g. bioenergy is not the main issue of the forest sector in which deforestation is a big general challenge to overcome). Recognition of different opinions would be needed as well as a sustainability path that is truly meaningful for society as a whole. Bioenergy should thus lead to real reduction of GHG emissions, and contributes to energy security and to local development in the short and long term.

- Promotion and dissemination of bioenergy benefits: five supranational stakeholders emphasised that communication of opportunities and concerns regarding the development of bioenergy to policy makers is important. The bioenergy actors should disseminate knowledge on the use of biomass for energy from scientific, technological, economic, social, and legal perspectives to external stakeholders. Also, it was considered important to advocate the abolition of any technical or trade barriers which hamper the development of an open bioenergy market. It was finally recommended that bioenergy actors demonstrate a clear and consistent approach of using efficient resources.

Bioenergy in the EU and target achievement

Four supranational stakeholders mentioned that EU policies have stimulated higher targets for renewable energy share and liquid biofuels in several countries, and that these targets will likely play a more significant role in the future. The development in the EU can provide perspectives for bioenergy development in other world regions. Consistent and long-term legislations would help to ensure long-term investments, whilst comprehensive sustainability criteria, robust certification systems, and implementation of best practices are also crucial for receiving more support.

Bioenergy in the short, medium and long term

Most supranational stakeholders highlighted that the development of bioenergy would depend on various factors. The perception, position of policy makers, and the policy framework are very important to pace the future development of bioenergy. Enhanced dissemination of the scientific findings, and under which circumstances bioenergy can make a positive contribution to sustainable development are key to support long-term policy formation

In the short term, most of the supranational stakeholders noted that showing compliance with established sustainability criteria and requirements is important. However, the current sustainability criteria for bioenergy are not sufficiently stringent and comprehensive to ensure adequate level of sustainability. Technological and investment risks of further bioenergy deployment have not been fully assessed. Therefore, in tackling these issues, implementation of more efficient markets and great trade flexibilities would help the bioenergy sector grow further.

In the medium term, most supranational stakeholders noted that bioenergy has a role in the renewable energy sector. They stated that the sector needs to focus on the technologies and deployments of advanced fuels. Technological development for processing and flexible measures to mobilise resources should also be further investigated.

Half of the supranational stakeholders were of the view that bioenergy use in heat and electricity will likely not grow significantly in the EU due to feedstock limits and lower conversion efficiency (particularly electricity). However in other regions of abundant biomass resources, heat and electricity generation from biomass would have the potential to grow strongly. Collaboration with other sectors of the bioeconomy needs to be enhanced for long-term development. In addition, sustainability criteria should take local context into account (e.g. FSC and PEFC establish global principles and standards but those principles are applied differently in each country after taking into account geographical, social, economic and environmental conditions).

3.3.4 Assessment of position, and level of interests and influence

This section included own interpretation of the authors on position of the stakeholder groups as well as the level of their interests and influence (see Figure 3.12). The round-table dialogues and interviews showed that most supranational stakeholders have a high awareness and expertise on global issues and a clear vision for bioenergy. Their reflection on the questionnaire results, their vision, and their answers to the key questions on bioenergy development also helped the authors to establish a conceptual sketch of the interests and influence of the different stakeholder groups.

The consultation results showed that awareness of the general public is low. Therefore their interest and influence is assumed to be minor. The environmental NGO groups in average showed a relative interest in bioenergy (when bioenergy is among the larger sectors on which they focus). The other NGOs representing the biomass producers and bioenergy industry were more neutral and supportive of bioenergy. Some environmental NGOs participated in the consultation showed a clear position about bioenergy development with some having concerns about environmental impacts of feedstock sourcing and mobilisation. We perceived that they also have relatively high influence through information and communication campaigns, with a capacity to change position of other groups. Some of them have critical view towards bioenergy. Certain biomass users for other purposes than bioenergy, such as biochemical and biomaterial stakeholders highlighted concerns over resource competition between bioenergy and their own sector. However, they indicated a limited influence on bioenergy development.

Biomass producers and biomass users for energy are generally interested in bioenergy, and they support bioenergy development. The biomass users for energy are agents working on bioenergy, and it was anticipated that their interest in bioenergy is high. However, their influence is not large, as they are also dependent on policies, long term governmental strategies, and targets for renewable energy. The academia and consulting group showed a high interest in bioenergy, which can also be explained by this being their working field. Given contradicting scientific reports and consultancies on benefits and impacts of the bioenergy sector, their influence on bioenergy development is not directly and not well recognised. Policy makers have the most important role in designing energy policies which influence the bioenergy development.

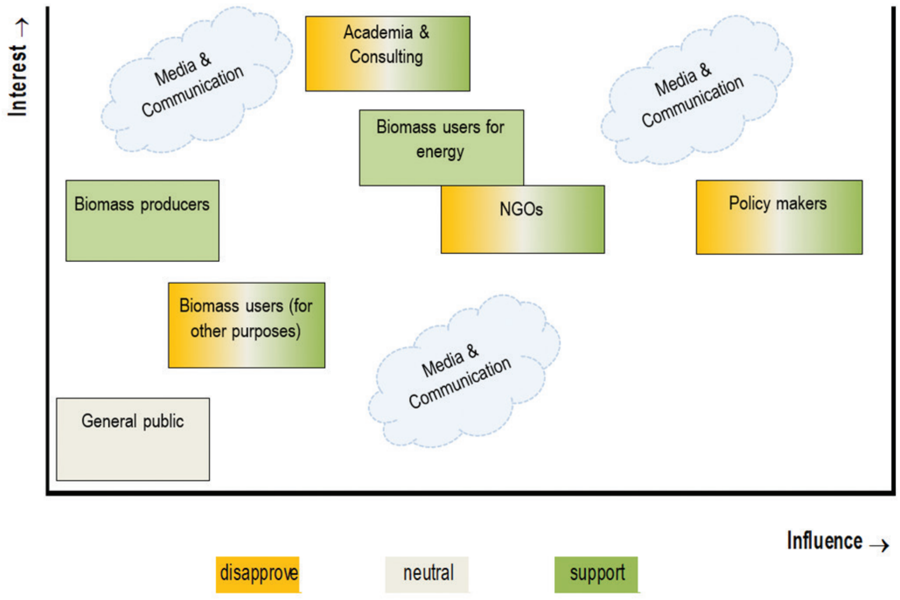

Figure 3.12. Conceptual sketch of interest and influence level of stakeholder groups

3.4 DISCUSSION

To put our results in a wider perspective, we compare them with regional case studies in Canada, Germany, and the US of the same project, as well as with some previous studies of the same focuses but with a more narrow consultation scope. We find that there are some prevailing points both from a global perspective and at a regional level. The points include sustainability governance, conditions for acceptance and benefits of bioenergy, as well as integration into bioeconomy.

> Sustainability governance and certification

This study confirms the importance of credible sustainability governance and certification at both global level and regional level. Sustainability governance helps to gain and enhance support for bioenergy and its development, which was also revealed in previous studies as well as in the regional case studies of the same project.[64,65,126–128] Results of two regional case studies indicated that certification and standards are also considered effective tools for ensuring sustainability governance.[126,127] However, governance of sustainable bioenergy systems is not a major concern when sustainability compliance needs to be demonstrated by law or public regulation. Furthermore, transparency and monitoring systems are considered important prerequisites to assure credible sustainability governance.[138] It also shows that a general sustainability framework can be designed at a global level. However, specific sustainability criteria should be tailored for different regions and sustainability measurements and applications need to consider local context.

> Acceptance and benefits of bioenergy

The study results reveal that overall, most participating stakeholder groups hold a relatively positive view of bioenergy; accept the bioenergy sector if sustainability conditions are met, and indicate potential benefits of bioenergy if developed in a proper direction. Both the conditions for acceptance and benefits include reduction of environmental impacts, conservation of wildlife and ecosystems, provision of aesthetic benefits, creation of local jobs, and contributions to local development. Similarly at regional level, income creation for individuals and companies as well as a creation of new business opportunities for local communities are found necessary to support bioenergy.[127,128]

> Integration into bioeconomy

Bioenergy and other bioeconomy sectors use the same or similar feedstocks and share similar supply chains. Therefore, integrating various bioeconomy sectors should be addressed. The integration helps to avoid resource competition between sectors, recover and reuse resources, whilst enhancing sectoral collaborations towards a long-term development. This aspect has also been confirmed by previous and regional case studies.[65,126,127] One example is the German biogas case study. In Germany, biomass is mobilised to produce biogas which is an integral part in the energy system, and used in the chemical industry and as a basis for the worldwide promoted bioeconomy. A rapid capacity growth in the biogas sector combined with a significant increase in meat production and thus fodder production fostered sustainability threats. A sustainable development of biogas therefore needs additional instruments such as a central system regulating the sustainability aspects of biogas apart from the agricultural sector, but also the better implementation of biogas in the further integration into the bioeconomy by going beyond the supply of renewable energies.

> Study limitations

While this study aims to be broad and comprehensive in its scope, it has some limitations. The results were based on data gathered from self-selected respondents, with the number and geographic distribution varying by category; they were not randomly selected from a well-defined population. This means that there are reservations to the interpretation of position and vision as representative for each stakeholder group. New studies may seek to complement the study by engaging more balanced contributions from specific stakeholder groups and from different continents.

3.5 CONCLUSIONS AND RECOMMENDATIONS

This study comprehensively addresses position and vision of various stakeholder groups including the supranational stakeholders, from local to global levels, towards bioenergy. It covers a broad scope of aspects and through the consultation with separate stakeholders groups, their position and vision are drawn more clearly compared to previous results.

Conclusions

The study reveals, among others, that the information and communication channels play important role to frame the position and vision of stakeholders towards bioenergy. The most trusted source of information (academic studies), rather than just media channels, should be strengthened as a basis for developing communication strategies. A continued dialogue and improved communication of scientific evidence of bioenergy's impacts and benefits to external stakeholders could help identify concerns and priorities of stakeholders, and find solutions acceptable for all parties. The potential benefits of bioenergy and its contributions to climate change mitigation, environmental improvements, social and economic enhancements, and to the bioeconomy if shown by scientific evidence, need to be translated into simple and clear messages to assist long-term decision making for the bioenergy sector as well as to inform the general public and other stakeholder groups.

Establishment of pathways toward sustainable development and a market-based growth of the bioenergy sector without governmental financial support is decisive to change the position of stakeholders. and gain more social acceptance of bioenergy and its potential contributions to sustainable development. Options to integrate bioenergy into the bioeconomy and establishment of sustainable supply chains are important for the sector to thrive further in the medium and long term.

To change the position of stakeholders, and ultimately to receive or enhance support for the bioenergy sector, sustainability criteria covering social, and economic and environmental aspects need to be mandatorily implemented for all types of biomass, regardless of end use, and are as such also applicable to the wider bioeconomy. Sustainability compliance and transparency is likely to be a solution for bioenergy to enhance support in the long term. However, it remains to be seen whether mandatory implementation will ultimately lead to more acceptance, and how realistic and rapid implementation for other end-uses is. The current certification schemes were not deemed completely credible and transparent by most stakeholder groups.

The sustainability requirements (GHG emission reduction, SFM, protection of high biodiversity values and carbon stocks, and social compliance), which are found in many voluntary schemes, are fundamental but have not met the expectation of all external stakeholders.

The stakeholders indicate the bioenergy sector to consider compliance with additional environmental, social, and economic aspects including ecosystem conservation, no competition with food production, and no violation of human and land rights. However, these sustainability aspects need to be defined and agreed upon by external stakeholders. Sustainability measures and certification will mean additional costs, adding to the high price of bioenergy relative to fossil alternatives. While these costs may be reduced with increasing uptake of sustainability certification, use of sustainable biomass needs to be also economically profitable and thus may require prolonged policy support.

Recommendations and study limitations

In addition to the key recommendations shown by the consulted stakeholders, there are certain aspects that the bioenergy sector should also consider. Stakeholders in the bioenergy supply chains are suggested to focus on mobilising what is perceived by stakeholders as sustainable resources, and further advancing of processing technologies, developing more effective supply chains, and ultimately reducing bioenergy costs to aid the sector to grow without subsidies and financial incentives. In addition to currently accepted feedstocks used for bioenergy, the revealed position of stakeholders suggest that additional feedstocks from sustainable bioenergy crops and forest biomass can be mobilised. Those feedstocks could potentially be harvested on surplus lands, by afforestation with low iLUC risks, through increased yield per area unit, and increased supply chain integration and efficiency.

We expect that these recommendations, if considered and implemented, will help to change the position of critical external stakeholder groups, and ultimately change their vision to positive perspectives of bioenergy development. The findings of the study can be used to inform interested stakeholders on the position of different groups on bioenergy, their awareness, and expectations regarding bioenergy development. The findings can also be considered by the bioenergy actors to better communicate the sectoral progresses to external stakeholder groups as well as consider external opinions and recommendations for their long term development.

SUPPLEMENTARY INFORMATION

S.I.3. Online questionnaire

Please specify your level of agreement with the statements below	*Strongly agree*	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
I am well informed on the bioenergy sector development					
In my opinion, the general public is sufficiently informed on bioenergy sector development					
The general public needs to be more involved in the development of the bioenergy sector, particularly in regions where bioenergy production takes place					
I believe that for designing bioenergy policies, public opinion is more important than factual base or scientific information					
I have a positive view of bioenergy in general					

I would support bioenergy development if it:	*Strongly agree*	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
Increases the security of energy supply					
Creates local jobs and economic development					
Reduces pollution of air and water					
Increases reuse and recycling of materials (therefore reducing waste)					
Improves management of soils and forests					

I would oppose bioenergy development if it:	*Strongly agree*	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
Leads to (indirect) land use change					
Does not reduce greenhouse gas emissions					
Competes for material use					
Over-exploits forest or leads to deforestation					
Leads to land right conflicts					
Does not improve local working conditions					

Most of my knowledge about bioenergy is derived from the following source(s) and the source(s) I trust the most are:	*Source(s) of information*	*Most trustful*
Internet and social media		
Television		
Journals/ magazines		
Local events/ news		
Non-governmental organizations		
Academia/ Consulting		
Bioenergy industry		
Colleagues/ friends		

Are you aware of similar efforts to understand stakeholders' perceptions, opinions and influence taking place in your country?

If yes, could you provide a source/reference:

Your organisation:

Which feedstocks should be used for bioenergy production:

»Agriculture: (Harvesting) crop residues (e.g. corn stover, rice straw)
»Agriculture: (Processing) crop residues (e.g. rice husk)
»Forest residues (e.g. thinning, clearing, logging from conventional harvest operations)
»Forest processing residues (e.g. sawdust, trimming, cut-offs)
»Urban wood residues (e.g. construction and demolition debris)
»Low-value wood (e.g. low-quality stems harvested as part of a conventional logging operation that do not meet the market specifications for sawtimber and have no other market from forestry plantation or natural forest)

Statements about gaining more support for the bioenergy sector:	*Strongly agree*	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
Sustainability requirements should be mandatory for all biomass types regardless of end use					
Current sustainability certification schemes/ systems for bioenergy are transparent and effective					
Policy makers decisions about bioenergy should be more based on scientific information					

Drivers of bioenergy development are:

	Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
Reduction of greenhouse gas emission					
Reduction of environmental impacts					
Making profitable businesses based on biomass					
Development of a circular economy					
Energy security/security of supply					

Major barriers for the bioenergy sector are:

	Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
Lack of economic stimulation/ market incentives					
Unresolved sustainability issues & resulting policy and market uncertainty					
Lack of scientific information for better informing policy makers & general public					

The biggest challenges for bioenergy production and supply chains are:

	Strongly agree	*Agree*	*Neutral*	*Disagree*	*Strongly disagree*
Lack of general societal acceptance					
Undesired environmental impacts cannot be avoided					
No contributions to economic growth					

We may contact you for a follow-up discussion. Would you agree with that?

»Yes
»No

Your organisation:

»Biomass producer
»Biomass user (for energy)
»Biomass user (for other purposes)
»NGO
»Academia and consultancy
»Policy maker
»General public

4

Sourcing overseas biomass for EU ambitions: assessing net sustainable export potentials from various sourcing countries

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4.1. INTRODUCTION

In recent years, many countries have made efforts to reduce greenhouse gas (GHG) emissions and to become less dependent on fossil energy supply through increasing renewable energy production.[92,139] One means of achieving those efforts is to increase the share of bioenergy, and as a result the role of biomass and bioenergy has become increasingly apparent in the energy mix in most EU countries and other developed regions in the last decade. In December 2015, 196 nations agreed to introduce measures and policies to globally reduce GHG emissions and to decarbonise the global economy in the Paris Climate Agreement. As of today, 152 countries have ratified the Agreement in which renewable energy sources, including biomass and energy efficiency, will play a key role.[140]

At present, many countries of the world are increasingly deploying and implementing renewable energy options, including bioenergy.[141] The European Union (EU) has set a target to collectively reach a share of 20% renewables in the final energy mix in 2020 and at least 27% by 2030. Japan, the largest importer of biomass outside the EU, has set a 22-24% renewables target share for 2030 [142] whilst Republic of Korea, the second largest importer of biomass outside the EU, aims for an 11% share of renewable energy in the overall energy mix by 2035.[59] Globally, biomass is the largest renewable energy source, and will continue to play a significant role in decarbonising the energy system.[143] Wood pellets, e.g. pre-processed products from various lignocellulosic biomass feedstocks, are increasingly used for power generation in many countries in recent decades, and can provide a stable source of low-carbon electricity. Biomass used for heat has grown more slowly due to limited policy support. Renewable energy in the EU in general, will be increasingly market-oriented and untapped potentials need to be exploited.[92,139,142,144,145]

To safeguard sustainable production and use of solid biomass for bioenergy as identified in various national and regional renewable energy targets,[59,141,142] sustainability requirements are to be applied. Within the EU, the European Commission (EC) issued a proposal for the new Renewable Energy Directive in 2016 to reinforce the existing EU sustainability criteria for bioenergy by extending their scope to cover biomass and biogas for heating, cooling, and electricity generation.[144] Sustainability requirements of lignocellulosic biomass used for heat and power production are already implemented in a number of Member States such as Belgium, Denmark, the Netherlands ,and the UK, the main importers of lignocellulosic biomass in the EU.

The EU is currently the largest producer and net importer of wood pellets.[146,147] In 2015, 20.3 Mt wood pellets were consumed of which 7.2 Mt were imported. By 2020, EU wood pellet imports from third countries are expected to be in the range of 15-30 Mt.[147] The EU import of wood pellets from non-EU countries in 2014 mainly came from the United States (US, 59%), Canada (20%), and Eastern European countries (19%).[148] In most scenarios with ambitious climate change mitigation targets, lignocellulosic biomass use in the next decades is expected to increase.[70,143,149,150] These scenarios show that that by 2030, the main exporting regions will likely be the same as today: the US, Canada, and Russia. By 2040, top-down models indicate a broadening of main exporting regions, with an increasing role for Latin America, Oceania, and Africa.[70,149]

With increasing demand for wood pellets and other lignocellulosic biomass in the EU but also in other parts of the world such as Japan, Republic of Korea, and India, additional domestic and imported resources will be needed. Focusing on domestic but also on new non-EU import regions is rational since this could reduce the energy dependence of the EU on some particular regions, and could help to mobilise unused, sustainably sourced, and residual resources. This article focuses on sustainable lignocellulosic biomass potentials, particularly residual biomass sources, in non-EU regions that have so far not contributed to the lignocellulosic biomass exports already in place. It follows a bottom-up approach and takes into account sustainability constraints, current alternative local use of biomass, and other local barriers.

Main objective

The main objective of this paper is to investigate six selected prospective international sourcing regions with promising sustainable biomass potentials that may be mobilised and exported to the EU between 2020 and 2030. This investigation includes the following tasks:

- **Assessment of sustainable export potentials:** an initial review of lignocellulosic biomass potentials in various countries revealed that a number of countries have high potentials of agricultural and/ or forestry residues and land availability for bioenergy crops. Six different case study regions were selected based on data

availability and local contact; high expected biomass potentials; promising logistic infrastructure and intercontinental transport; variation of socio-economic and environmental constraints. The six case studies, on 5 different continents, are Kenya, Indonesia, Colombia, Brazil, the US, and Ukraine.
- **Analysis of the cost and GHG emissions along the supply chain:** Cost supply curves and GHG emission supply curves were generated for wood pellets produced in the six case study regions and transported to the port of Rotterdam, the Netherlands.

4.2 METHODOLOGY

The potentials assessed in this analysis include the technical potentials of lignocellulosic biomass, the sustainable potentials, calculated by including sustainability criteria, the sustainable surplus potentials which takes into account domestic demand in sourcing countries, and the export potentials which are the amount of sustainable biomass that could be available for export to other world regions such as the EU (see Figure 4.1). A general and comparable assessment approach for potentials was applied in all case study regions, allowing for a comparison of sustainable export potentials, based on similar criteria.[151,152]

To qualify the lignocellulosic biomass that can be mobilised for exports, a number of pre-requisites were formulated:[153]

- ***Sustainable sourcing*** is a precondition for all exported lignocellulosic biomass, and for all domestically sourced biomass, the sustainability principles and criteria that are already implemented in the EU are considered.
- ***Local demand for both energy and material purposes gets priority over export***. Thus, domestic demand of biomass should be satisfied first before exploring exporting options. In this way it avoids distortion of local markets.
- ***Emissions from the entire supply chains of biomass*** should lead to substantial chain reduction in comparison to the fossil fuel equivalence.
- ***Performance-based sustainability requirements*** need to be applied on the entire value chains (including production and logistics) up until the import harbour.

The following section briefly discusses the applied methodology to calculate the potentials, supply chain costs and supply chain GHG emissions.[151]

4.2.1 Methodology to calculate potentials

In view of limited time and resources, the first methodological step was the selection of the case study regions with the highest biomass potentials within different countries, and the potential mix of biomass resources to be analysed per region (see Figure 4.1 and S.I.4.1 for more details).

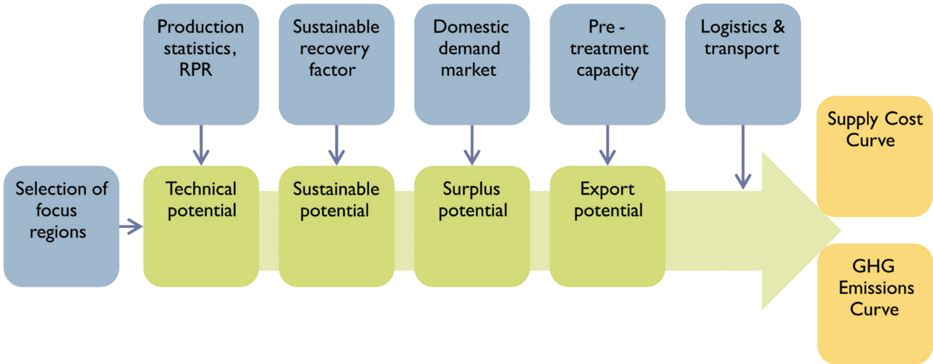


Figure 4.1. Methodology to calculate the different potentials

In the six case studies, different feedstocks were included, following local opportunities (see Table 4.1). Primary agricultural residues are residues generated in the field during harvesting processes, whereas secondary residues are generated at the processing stage. Primary forestry residues are residues originating from harvesting or forest management practices, such as logging and thinning, typically left behind in either natural or plantation forests. Secondary forestry residues originate from the processing of forest products, and include for instance saw mill residues. Dedicated energy biomass is the production of either energy crops such as switchgrass or miscanthus, or forestry biomass, dedicated to the production of (lignocellulosic) biofuels.[78]

Kenya was the first case study in which the methodology was applied, including an investigation of all types of biomass, agricultural residues, energy crops, and forest residues. This case study however showed very limited potentials from energy crops and forest residues, after which it was concluded that the remaining case studies would focus on the most promising potentials in the respective regions. For the Brazil case study, the availability of agricultural and forestry statistics allowed for the inclusion of both these feedstock types. In Indonesia, more than 50% of the land is covered by natural forests, which are for biodiversity reasons protected. Considering the sustainability risks in Indonesia, only residues from certified palm plantation areas or land under governmental support were included.[154] In Colombia, although more than half the land is covered by forests, the potential for forestry biomass is assumed to be low since most of the forests are biodiversity rich, and protected areas. For this reason, the Colombian case study focused solely on agricultural residues.[155] For the case of the Ukraine, there was access to detailed data on the potential for energy crops.[156] For other case studies this data was not available. In the US case study, the calculated potential was based on existing practices. By far the largest share of pellets produced in the case study region in the US is produced from forestry residues and forestry products such as roundwood. Therefore the US case study will focus on these residues.[157]

Table 4.1. Feedstocks included in case study countries

		Brazil	Colombia	Indonesia	Kenya	United States	Ukraine
Agricultural residues:	*Primary*	X	X	X	X		X
	Secondary		X	X	X		
Forestry residues:	*Primary*	X				X	X
	Secondary	X					X
Dedicated energy biomass:	*Agriculture*						X
	Forestry					X	

In the second step, the **technical potentials** was calculated, which follows the definition of potentials in the Biomass Energy Europe project,[158] and is defined as *the terrestrial biomass considered available under the current techno-structural framework conditions with current technological possibilities (such as harvesting technologies, infrastructure and accessibility, and processing technologies), while also taking into account spatial confinements due to other land uses (such as food, feed and fibre production, nature reserves).* The technical potentials (P_T) in the different case study regions were calculated using formula (1) based on production statistics of agricultural and forestry products combined with residue-to-product ratios (RPR), or from literature on the production of lignocellulosic biomass or residues per hectare.

$$P_T = A_i \times Y_i \times RPR \times E_i \qquad (1)$$

where A_i is the crop area of crop i in the case study region, Y_i represents the yield of crop i in the case study region, RPR is the residue to product ratio and E_i is the energy content of crop i in the case study region (LHV).

The **sustainable potentials** (P_S), *defined as the share of the technical potentials which meet environmental, economic and social sustainability criteria,*[158] was calculated in the third step. An assessment was made per region and feedstock, based on literature and local expert opinions, of the sustainable land availability and sustainable recovery factor (SRF) of residues and energy crops. By applying restrictions on the harvestable area and removable biomass shares, the sustainable potentials were calculated using equation (2). The basic sustainability requirements included in all case studies are closely aligned with the requirements of the Renewable Energy Directive (RED I).[159] Additional requirements were included in some case studies based on data availability and relevant local sustainability criteria. The residue to product ratio, energy content per feedstock and sustainable recovery factors used per case study country and feedstock are presented in S.I.4.2.

$$P_S = P_T \times (1 - L_S) \times SRF_i \qquad (2)$$

where L_S is the fraction of land excluded because of sustainability criteria (such as high biodiversity areas), and SRF_i represents the Sustainable Recovery Factor of crop i in the case study region, the factor of residues that can be extracted while meeting sustainability criteria.

The **surplus potentials** (P_{SS}) were calculated in the fourth step. These were *defined as the potentials which could be available for export to other regions, after subtracting current and expected future local demand for biomass for material and energy applications, covering industrial and residential utilization*. Based on local expert opinions, the percentage of primary and secondary residues used locally was subtracted from the sustainable potentials to form the sustainable surplus potentials. The local demand in the different case studies is presented in S.I.4.3.

$$P_{SS} = P_S - LD_i \qquad (3)$$

where LD_i represents the local demand of crop i in the case study region.

In the fifth step, the **export potentials** (P_E) were calculated, *defined as the potentials which could be exported, taking into account requirements such as the availability of transport infrastructure and pre-treatment plants*. Lignocellulosic biomass needs to be pre-treated and densified before it can be transported across long distances. This is, amongst others, done to reduce safety risks related to self-heating and microbial hazards, but also to improve handling properties, and reduce the cost and energy requirements of transport. As default pre-treatment technology, pelletization of woody and agricultural biomass was assumed since this is the pre-treatment technology most commonly used for lignocellulosic biomass.[160] The future pelletization capacity was estimated by analysing current capacities (if any) and growth curves of production capacity in the respective countries and by considering potential capacity growth rates. Acknowledging this requirement, the availability of pellet production facilities was taken into account as limiting factor to calculate the export potential.

$$P_E = MIN(P_{SS}, CY_P) \qquad (4)$$

where CY_P is the pelletising capacity in the case study region.

In the final step, to calculate the costs and GHG emissions of exported lignocellulosic biomass, transport routes from case study regions to the EU were designed and calculated. The port of Rotterdam was chosen as import point, because of its central location in the EU and the good port facilities, making it an interesting potential import hub for lignocellulosic biomass energy carriers. Based on the export potentials, the costs of delivering lignocellulosic biomass to the port of Rotterdam, as well as the emitted GHG emissions were calculated, including feedstock cultivation, pellet production, inland transport and transport to Rotterdam. Cost supply curves and GHG emission supply curves were generated to account for differences between different supply regions and feedstocks.

4.2.2 Supply chain cost calculation

Supply chain costs were calculated using equation (5) by taking several components along the chain into account, while combining country specific data and uniform cost assumptions.

$$C_D = C_P + C_{Tdf} + C_{Pt} + C_{Tdp} + C_{Ti} + C_H \qquad (5)$$

where C_D is the total production cost of biomass, C_P is the cost of feedstock production, C_{Tdf} is the cost of domestic transport from the fields to pre-treatment facilities, C_{Pt} represents the cost of pre-treatment, C_{Tdp} is the cost of domestic transport from pre-treatment facilities to export location, C_{Ti} is the cost of international transport from export locations to the port of Rotterdam, and C_H represents the cost of handling and storage.

Most of these cost parameters were taken from literature. In some cases, field research and interviews with experts provided country specific parameters. The cost factors used in the different case study countries can be found in S.I.4.4.

Transport cost to the pre-treatment facilities (C_{Tdf}) was calculated by including road transport over 50 km. The production cost of pellets (C_{Pt}) was based on Ehrig et al.[161] Cost of some consumables such as spare parts were included based on Pirraglia et al.[162] The cost structure of pre-treatment is assumed to be similar in the different case studies. In most of the case study countries, there is no large-scale pellet production yet; making it difficult to assess potential cost, therefore, the decision was made to base the cost for all countries on the same data sources. A number of country specific cost factors are included in all case studies, such as the cost for electricity, labour, and feedstock. In case of the Colombian case study, data limitations prevented the calculation of cost based on country specific factors. Instead, total pelletization costs were assumed based on the other case studies.

Cost of transporting pellets to export ports was calculated by taking the distance from weighted centres of regions to export ports. For most case study regions, this was done based on a first-level administrative division (typically state-level); for the US, this was done on a second-level basis (i.e. county level). Road transport was assumed in most of the case studies, since rail networks are often not or very poorly developed. For the Ukraine and the US, rail transport is a viable option for some locations. For these two countries, it was possible to calculate the transport cost in more detail by making use of the existing BIT-UU model.[163] The BIT-UU model is a GIS-based biomass transport model with an intermodal network structure of road, rail, inland waterways, short sea shipping in Europe, and ocean shipping. The model combines linear optimization of the allocation between supply and demand nodes with global input data on cost for transport of lignocellulosic biomass. The cost of international transport (C_{Ti}) was calculated by making use of the BIT-UU model where possible. For countries that are not included in this model, these costs were calculated through a web-based sea freight calculator.[164]

4.2.3 Supply chain greenhouse gas emission calculation

To determine GHG emissions for each stage of the supply chain, global warming potentials were estimated from electricity, fuels, and materials use. The calculation of GHG emissions closely followed the EC approach.[92] When actual data were not available, default values provided by the EC and other references were applied.[92,165]

The GHG emissions were calculated according to formula 6:

$$E = E_{ec} + E_s + E_p + E_{dt} + E_{it} \qquad (6)$$

Where E_{ec} is the emissions from cultivation (applied only for energy crops), E_s represents the emissions from nutrient replacement (including emissions from production and use of fertilizer to compensate for biomass removal, which leads to the emissions of GHGs via chemicals use), E_p is the emissions from pre-treatment (including chipping, drying and pelletization), E_{dt} is the emissions from domestic transport, and E_{it} is the emissions from intercontinental transport to the Port of Rotterdam.

Analysis of potential GHG emission savings was made by comparing emission avoidance in relation to production of electricity and heat from fossil resources. In order to compare the GHG emission savings with fossil fuel alternatives, the RED I was used. Where forest or agriculture residues are considered, the required GHG emission savings in the EC are, in principle at least 70% compared to fossil fuel alternatives. However, lower savings can occur for short-rotation coppices (e.g. eucalyptus in tropical countries), in case of low fertiliser use in agriculture, and when natural gas is used for drying pellets.[165] It is therefore considered to be good practice for existing bioenergy installations to achieve GHG emission savings of at least 70% compared to the fossil fuels comparators. This equates to lifecycle emissions of less than or equal to 12.8 g $CO_{2eq.}$ /MJ_{el} for electricity, and 34.1g $CO_{2eq.}$/MJ_{el} for generated heat. In the more ambitious

EC pathway, the GHG emission savings should be 80% lower, equal to 10.6 $gCO_{2eq.}/MJ_{el}$ for electricity and 28.4g $CO_{2eq.}/MJ_{el}$ for generated heat in a co-firing heat and power plant (CHP).[165,166]

4.2.4 Scenario development

One of the key aims of the analysis presented in this paper was to investigate future markets and opportunities for sustainable lignocellulosic biomass feedstocks. This depends on aspects such as technological and economic developments and changes in climate, energy, agricultural and business policies. To anticipate the possible changes in biomass trade, and market developments, two scenarios were designed for 2020 and 2030.

The Business As Usual (BAU) scenario was based on a continuation of historic and current trends. The BAU scenario was built on current and expected policies in climate and environmental policies in the sourcing regions. Historic feedstock production trends in most countries show an increase in production area and yield. These trends were assumed to continue in the BAU scenario. The sustainable potential calculations were based on current feedstock extraction rates, taking into account existing sustainability restrictions. The domestic demand for different feedstocks was estimated using statistics where possible, and in consultation with local field experts otherwise. The BAU scenario took into account trends in local use, for instance local use of residues for energy production. Continuation of pellet production capacity growth trends was applied in the BAU scenario where possible. In case the growth of production capacity was unclear, growth of pellet plant capacity was based on worldwide growth estimates.

The High Export (HE) scenario explored options under which larger volumes of sustainably produced biomass might become available for export. These may include an assessment of possibilities to increase the yields of biomass production, of additional land availability for biomass production and of reduced local demand for biomass. Agricultural and forestry production was assumed to follow optimistic growth trends, including improved yields as a result of better management practices and higher fertilizer use.

For the calculation of the surplus potential, the lower ranges of expert assessment of local demand of feedstock were used. The growth rates for pellet plant capacity were assumed to be higher in the HE scenario. As a maximum growth rate, the recent historic growth rates in the US were taken, which showed a very high increase from 160 ktonne in 2006 to 4,800 ktonne in 2013.[167] The growth rates in specific case study countries were modelled to the US growth rates starting from the period with similar total production volume.

4.2.5 Case study assumptions and specific adaptations

The calculation of potentials in each case study was largely determined by availability of statistical data, literature, and access to local experts. Assumptions were made based on literature and expert consultations. In some case studies, it was necessary to diverge from the general methodology due to data limitations or case specific situations that justified an adapted, more suitable approach. The most important case specific adaptations to the general methodology will be discussed below.

In Brazil, the technical potential was restricted by land suitability, consisting of technical and non-technical constraints, according to Verstegen, Van der Hilst & Woltjer.[168] This entailed that certain restrictions were already partially included in the additional technical potential towards 2030. This restriction had a larger effect in the HE scenario considering the assumptions of larger increases in yields and agricultural areas.

In Colombia, the calculation of the sustainable potential fully excluded oil palm trunks and leaves, as experts deemed collection as prohibitively costly. This could limit the sustainable potential by more than just the residue fraction needed to cover sustainability criteria. Furthermore, since reliable information about pellet production capacity was not available, pellet plant capacity was not considered as a limiting factor.[155] For this reason, the only results shown for Colombia were the surplus potentials, and not the export potentials. Cost supply curves were calculated based on the surplus potentials.

In Indonesia, the yield of agricultural crops in the HE scenario was assumed to be higher than in BAU, and increased over time until 2030. At the same time, the rate of residue removal was supposed to increase, since fewer residues are needed for soil protection and to maintain soil organic carbon levels as a result of improved crop management.[169]

In Kenya, just as in the Colombia case study, pellet production capacity was not considered as a limiting factor since data about pellet production was not available. Similarly, cost supply curves were calculated based on surplus potentials.

In Ukraine, agricultural production has varied strongly in the past years. Future investments in the agricultural sector in Ukraine were uncertain due to the difficult political and economic situation resulting from the Ukrainian Revolution of February 2014. The assumption was made that the total agricultural production volume remains unchanged both in the BAU and the HE scenario. The amount of residues needed to maintain SOC levels was modelled by applying the Rothamsted Carbon model to calculate the soil carbon balance.[170–172] The model input was taken from the MITERRA-EUROPE model. The database used in this model is on NUTS 2 level and includes relevant data such as land use, crop type, soil type, and topography.[173] Data on soil organic carbon levels was retrieved from the European Soil Database.[174] In the HE scenario, the assumption was made that the residue removal rate increases gradually until 2030 as a result of improved management practices and the application of fertilizer, except for those regions in which the removal rate is 0%.[156,175,176] In Ukraine, a significant potential for dedicated energy crops was assumed, based on a study of Van der Hilst et al.[156] This study analysed the bioenergy production potential in Ukraine as well as related GHG emission balances of land-use change. In this study, the demand for food and feed was calculated in a BAU and progressive scenario, in 2020 and 2030, as well as the land required to meet this demand. The bioenergy potential was calculated based on the production of switchgrass on land still available after accounting for this existing demand.

In the US, the focus is on the South East, which is the most important pellet exporting region within the US.[177] Pellet production was based on forestry feedstocks, among which logging residues, mill residues, and pulp logs, making up only a small percentage of the total wood market.[178] By applying sustainability criteria only for wood used for energy purposes, the risk of leakage exists; wood sources meeting the criteria can be (re-)allocated to biomass purposes, whereas non sustainable sources could be used for other purposes not covered by sustainability schemes.[152] This effect is to be avoided in order to ensure overall sustainable harvest practices. Therefore, a slightly different approach was used in the US case study. In the calculation of the sustainable potentials, only the biomass used for pellets was limited by the sustainability criteria.

In the calculation of the surplus potential however, the assumption was made that the entire domestic demand for biomass, that was the existing wood market, must also meet the sustainability criteria.[152] The availability of pellet equipment was not included in the calculation of the export potentials. The pellet market in the US was well developed; large historic growth rates have shown that the industry was capable to respond quickly to market developments. Therefore, the pellet plant capacity was considered to develop in response to market developments, and was not included as a limiting factor in the calculation of export potentials.[152]

4.2.6 Data collection

Data for the calculation of the different potential was gathered from a combination of sources. Statistical data on agricultural and forestry production was combined with data from literature, for instance on sustainable restriction. As much as possible regionally specific data was used to calculate the different potentials. Data from literature was, where possible, supplemented by assessment from experts in the case study regions.

The technical potentials in all case studies were based on production statistics on a state level, or higher resolution. The sustainable potentials were in some cases based on regionally specific input, such as in the Ukraine and US case studies. In other case studies, such as in the Brazil study, data availability made it necessary to use default values for the entire case study. Data on the domestic demand of different crops was largely based on personal communications with local experts, and was assumed to be similar for all regions.

4.2.7 Sensitivity analysis

The calculation of potentials, costs, and GHG emissions in the different case studies involved the making of several assumptions and the use of uncertain data. The two different scenarios reflect the uncertainty in the future development of biomass potentials, costs, and GHG emissions. To furthermore analyse the impacts of data uncertainty, sensitivity analyses were carried out for the supply potentials, supply costs, and supply GHG emissions by varying several factors that strongly impacted the calculations.

The preferred method of obtaining minimum and maximum values for selected parameters was considered from available literature. In case no data could be found in literature, a three tier uncertainty system was applied with low, medium and high levels of uncertainty reflected in different uncertainty ranges of 10%, 25%, and 50% for export potentials and costs; and of 5%, 10%, and 20% for GHG emissions. The uncertainty for GHG emissions were assumed lower because in practice, there is less fluctuation in the three impacting factors used for GHG emission calculation (nutrient substitution, local transport and electricity use). In order to assess the level of uncertainty, interviews with experts, where possible from the specific case study regions, were used.

4.3. RESULTS

First, to show the results of applying the different methodological steps to calculate the export potential, the results from one case study are highlighted in section 4.3.1. To this end, the case study of Brazil was considered to be a good example for several reasons. Most importantly, the availability of locally collected data allowed for the application of all the steps of the general methodology. Furthermore, the domestic use of biomass, specifically for energy production, was increasing in this country. This results in clear differences between the scenarios and timelines as the domestic demand were increased. The situation in Brazil therefore evidently shows the effect of applying different constraints, while varying these constraints in different scenarios.

In section 4.3.2, an analysis of the overall results of all the six case studies are shown, focusing on the differing export potentials under different timelines and scenarios, as well as the respective cost supply curves and the greenhouse gas supply curves.

4.3.1 Results from Brazil case study

The technical potentials of agricultural and forestry residues show the importance of sugarcane residues, especially from São Paulo state, accounting for 43% of the total technical potentials (see S.I.4.5 for a map of all included states). The sustainable potentials were calculated by applying a sustainable recovery factor (SRF); see equation 2. SRF values for Brazil were obtained from literature research, and for sugarcane, cross-checked through interviews with local experts (Roozen A, personal communication).[179–186] The SRFs obtained from literature were derived from field experiments investigating the effects of residue removal on soil nutrient balance, soil erosion rates, and soil organic carbon percentages. The chosen SRFs represent a removal rate at which these sustainability indicators are not negatively impacted. The SRFs are impacted by local conditions, such as soil type, slope and climate, there was however no data available on geographically specific SRF factors. To overcome this problem, a default SRF was used for the entire case study region, drawing from literature on sustainable residue removal in Brazil.[187] This default can be considered conservative, case studies on the removal of rice, soybean and corn residues in Brazil showed removal rates that are higher than the default removal rates used in this study.[188–190]

The residue recovery limitation did not apply to processing residues such as bagasse, rice- and coffee husks, and orange peels, which can be 100% utilized. The sustainable recovery factors of the different feedstocks can be found in S.I.4.3 since the use of sugarcane bagasse is not restricted by sustainability criteria. The relative contribution of sugarcane to the sustainable potentials was even larger, with sugarcane bagasse accounting for 56% of the total potentials (see Figure 4.2).

Figure 4.2 shows the sustainable and sustainable surplus potential of the different residues in Brazil. Sugarcane bagasse is predominantly used already for the production of local electricity and heat. Currently 90% of the bagasse is used locally to provide electricity and heat to sugarcane mills, and excess electricity to the power grid (A.Roozen, personal communication). The demand for local residues used to produce electricity was expected to increase significantly based on expected increased contribution of bioelectricity to Brazil's energy needs from 3% to 18%.[191]

Considering this strong pull towards local use of sugarcane bagasse, the assumption was made that the remaining residues that can technically be harvested will, in the future, be used locally as well. The additional assumption was made that residues that do not meet the quality standard required for local production of electricity or heat, will neither meet the criteria required to produce pellets, and are therefore considered unavailable. Therefore the local use of sugarcane bagasse was assumed to increase to 100% in the BAU 2030 scenario.

In the past, sugarcane straw has predominantly been burned in the field. In recent years, federal governments, with São Paulo being the first, have banned this practice to limit damage to the environment and surrounding villages.[192] The common practice changed to piling up the sugarcane stalks in the field. Partial straw removal from the field for additional electricity production has begun to take place. These trends, as considered by local experts, will likely result in increased local use of residues towards 2030.[193] To account for the uncertainty in these developments, the domestic demand was considered varying: demand was assumed to increase from 0% in the current situation towards 50% in the BAU scenario, and 25% in the HE scenario in 2030. After considering the domestic demand for residues, the total sustainable surplus potential was reduced to just 17% of the sustainable potential in 2030 in the BAU scenario, and 31% in the HE 2030 scenario.

The last limitation applied was the availability of pellet plant capacity needed to densify the residues. The current potentials were calculated based on the capacity of existing plants.[194] The capacity in the case study regions was, at the time of investigation, 630 ktonnes per year. A capacity factor of 80% was used to calculate the actual pellet producing capacity. This is considered optimistic, since in reality, pellet plants often run at lower capacity because of supply limitations.[195]

As data about expected growth rates of pellet production capacity was not available, estimation about future capacity in the BAU scenario was based on world-wide pellet capacity developments expected between 2015 and 2023.[196] This growth was expected to continue until 2030. For the HE scenario, the assumption was made that the pellet plant capacity increases with growth rates modelled after historical pellet capacity growth in the US.[197] This results in an annual export potential of 71 PJ in the BAU scenario, and 411 PJ in the HE scenario in 2030.

The newly added pellet capacity was assumed to be divided according to the surplus potential in each state. Until 2020, pellets were assumed to be produced from forestry residues; the sustainable surplus forestry potential exceeds the pellet plant capacity. After 2020, agricultural residues were assumed to make up a share of 30% of the additional pellet production capacity, increasing in some states where there is a limited supply of forestry residues.

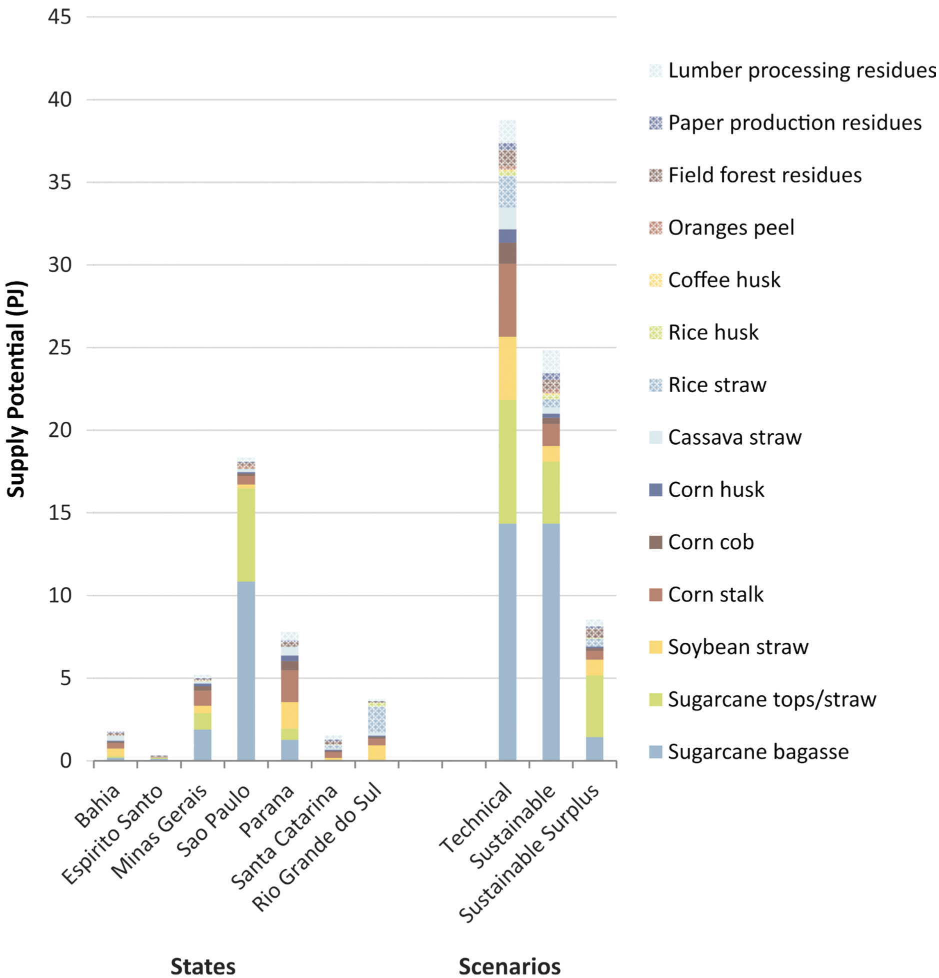


Figure 4.2. Technical potentials of current scenario, per feedstock and region; technical, sustainable and sustainable surplus potentials of current scenario in Brazil

4.3.2 Limiting factors

The extent to which specific constraints limit the various potentials varies between case studies, reflecting amongst others differences in sustainability concerns, domestic uses of biomass, and the maturity of wood pellet production markets. In this section, the main limiting factors per case study country are discussed.

In Brazil, the potentials were limited by the local use of sugarcane residues for the generation of heat and electricity, corn stover, and cassava straw for cattle feed, rice, and coffee husk for chicken bedding, and oranges peel for citrus pulp pellets (A. Roozen, personal communication).[198–203] A lack of railway infrastructure increases the cost of pellet export and the export potentials were limited by the lack of pre-treatment technology, the existing pellet capacity was very small in Brazil and the focus was on ethanol instead of pellets.[194]

In Colombia the potentials were reduced by the use of palm residues for compost production and the use of sugarcane bagasse for co-generation to generate process energy in sugar and ethanol mills. Poor infrastructure limits the mobilization of field residues, increasing the cost of transporting pellets from inland areas. High mineral and moisture content of residues limits the production of pellets. A lack of pellet plant capacity limits the export potentials in general, no pellet plants exist in Colombia as of yet and data on pellet capacity development was lacking.[204]

The potentials from Indonesia were limited by the local use of palm residues for electricity production at palm oil mills and the use of palm fronds as fertilizer at palm plantation sites. Sustainability concerns of expanding palm plantation areas, especially at areas not under governmental support, results in excluding these areas from the sustainable potentials. No pellet plants existed in the investigated regions in Indonesia, limiting the export potentials. At the same time, capacity was assumed to grow at a fast pace, considering the possibility to integrate pellet production in existing and growing oil mills.[205]

In Kenya, avoiding soil erosion and nutrient depletion is an important issue, resulting in a low SRF. The use of agricultural residues for cattle feed, and forest residues for cooking, reduces the surplus potentials. Large distances from production regions to the Mombasa port, and poor quality of infrastructure, increases the cost of exporting pellets. No pellet plants existed in Kenya, and no data was available on pellet capacity development, limiting the export potentials. [206–208]

In some regions in Ukraine, the SRF factor is low. In many regions, 100% of the maize straw can be removed, with stubbles, chaff and belowground carbon being sufficient to maintain SOC levels. Removal levels for barley straw are however generally low, below 45%. Levels for rapeseed, sunflower and wheat vary between 0% and 100% per region.

Historic growth rates of pre-treatment capacity were low, therefore pellet capacity was assumed to remain a strong limiting factor.[209]

In the US, sustainability requirements were considered to apply to the entire US wood market, forming the main limiting factor. This in order to avoid nutrient depletion and biodiversity loss, and to avoid unsustainable shifts in harvest practices.[210]

4.3.3 Combined case study results

Results show a very large technical potentials of lignocellulosic biomass supply in 2030, especially in the form of energy crops from Ukraine and agricultural residues from Brazil, as seen in Figure 4.3. Due to several restrictions applied in this study, the sustainable, sustainable surplus, and export potentials were considerably smaller. In the BAU scenarios, the local demand for biomass formed the largest restricting factor, with the pre-treatment capacity being an important limitation as well. In the HE export, the limited increase over time of pre-treatment capacity formed the main limitation.

The overall export potentials increase strongly in the HE scenario towards 2030, due to the high assumed annual growth rates of pellet production capacity. In 2030 in the HE scenario, Brazil contributes 27% to the total potentials, Indonesia and the US each 30%, and Ukraine 13%. Since the export potentials could not be assessed in the case studies of Colombia and Kenya, these countries are left out of consideration.

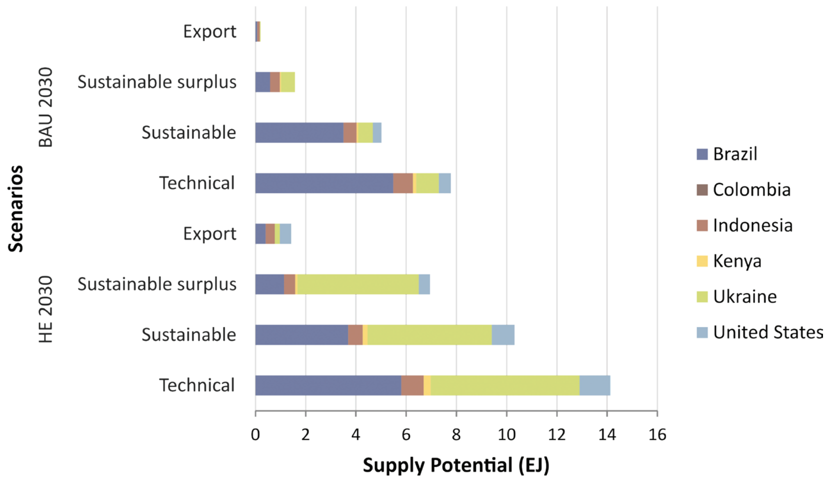


Figure 4.3. Technical, sustainable, sustainable surplus, and export potentials in the different case study countries - BAU 2030 and HE 2030

4.3.4 Cost Supply Curves

When looking at the cost supply curves (Figures 4.4 and 4.5), there is a large difference between the case studies. The least expensive lignocellulosic biomass can be imported from the Ukraine, the cheapest residues being 6.4 €/GJ. Delivery cost from Indonesia (from 11.8 €/GJ) and Brazil (from €10.8/GJ) are significantly higher. The cost of lignocellulosic biomass from the US in the HE scenario starts off reasonably low at €7.8/GJ and stays under 15 €/GJ for 400 PJ (about 90% of the total export potential).[210] The steep increase in costs towards the end of the US cost supply curve is the result of the modelling of cost of forest thinning from areas with poor or no road access. Increased "distance to road" results in very expensive biomass, which in reality would not likely be harvested, but is still available for use.[210,211] The US case study furthermore includes incremental costs for additional feedstock supply, resulting in a sharp increase in feedstock cost towards the maximum supply potential as identified in this case study.

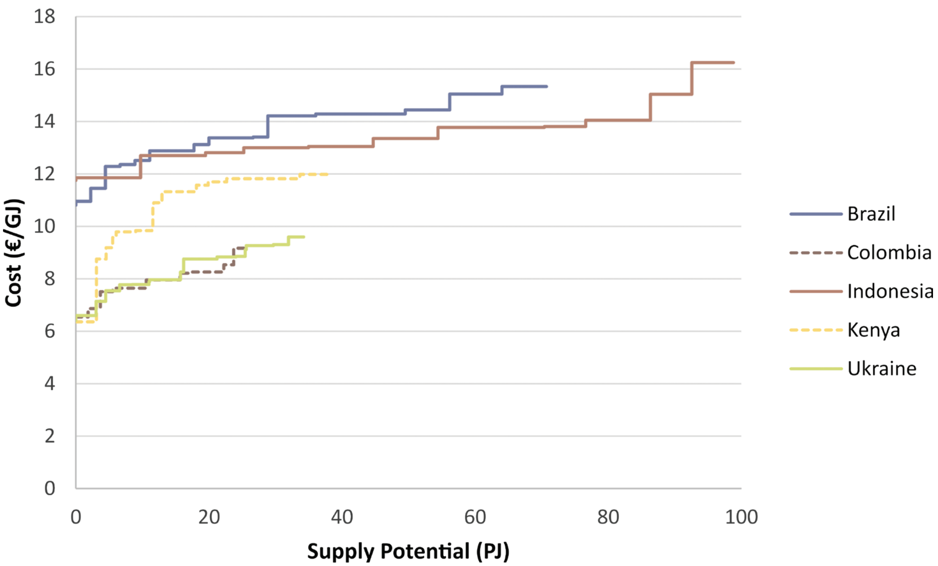


Figure 4.4. Cost supply curves of export potentials (Brazil, Kenya, Ukraine – solid lines) and sustainable surplus potentials (Colombia, Kenya – dashed lines) delivered to the Port of Rotterdam in the BAU 2030 scenario

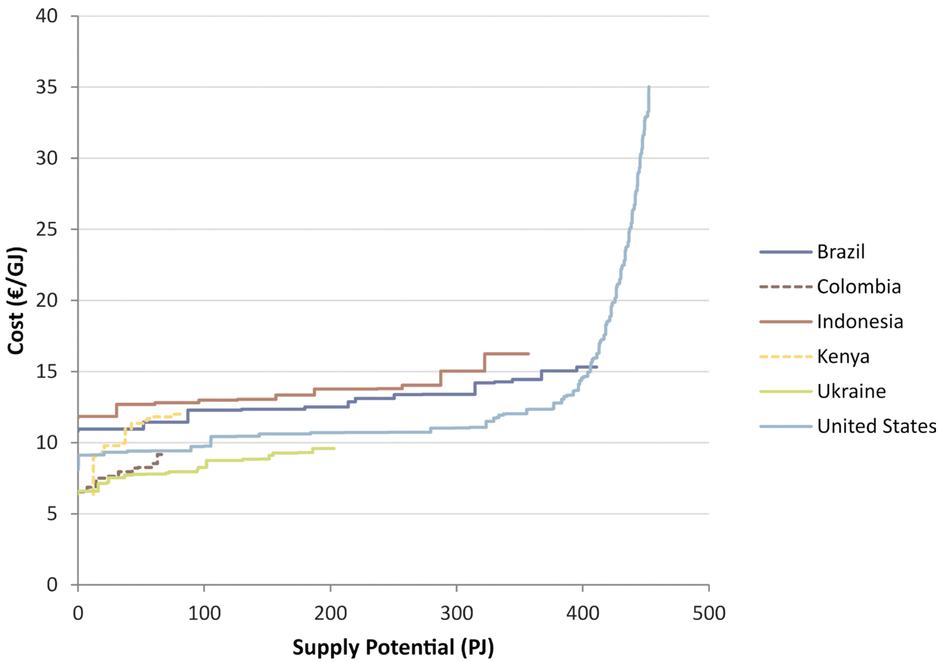


Figure 4.5. Cost supply curves of export potentials (Brazil, Kenya, Ukraine, United State - solid lines) and sustainable surplus potential (Colombia, Kenya - dashed lines) delivered to the Port of Rotterdam in the HE 2030 scenario

4.3.5 Greenhouse gas emission curves

The calculations of GHG emissions show that average emissions from the US are the lowest, emissions from Kenya, Ukraine, Brazil, and Colombia are higher but the highest values are for Indonesia (Figure 4.6). In the Colombia case study, the emissions of pre-treatment were assumed to be zero since residues were considered to be used for the production of energy for plant operation and maintenance activities, which resulted in no GHG emissions. In practice, there are still emissions due to diesel use for machinery and the use of electricity from the national grid in the pre-treatment plants. In order to easily compare the results with other case studies, a GHG emission factor from electricity production was taken into account in Colombia, following the BioGrace II default values.[212]

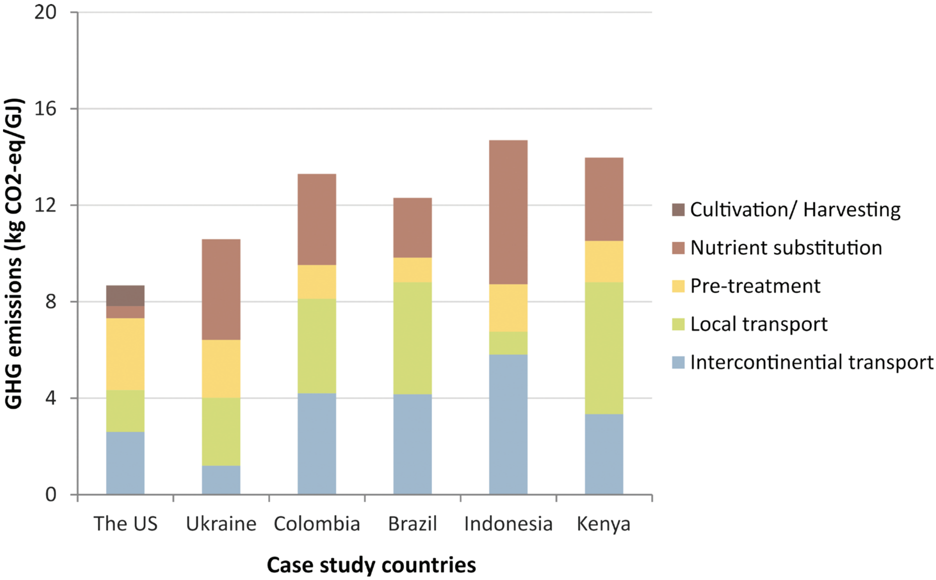


Figure 4.6. Average greenhouse gas emissions of lignocellulosic biomass supply chains in different case study countries

With shorter intercontinental transport routes to the import harbour of Rotterdam, Ukraine has the lowest international transport emissions. Indonesia has the highest transport emissions, due to the long transport distance to the EU. The emissions of local transport are highest in Kenya and Brazil. In both countries, the state of infrastructure was poor, and the distance between sourcing regions to the export harbours was large. Emissions from pre-treatment plants are highest in the US and Ukraine, mainly due to the high electricity emission coefficients in those countries. Emissions from nutrient substitution are highest in Indonesia and Ukraine due to higher fertilizer use to substitute the removed residues for soil organic carbon. The US is the only country where cultivation and harvesting are taken into account, since the collection of forest residues is a well-regulated activity in which emitted GHG emissions are recorded.

In both BAU 2030 and HE 2030, the potential supply from all the case studies meets the current 70% and proposed 80% cut-off reference for heat as set by the current and revised RED (34.1 and 28.4 kg CO_2/GJ respectively in co-firing heat and power plants). When using the current 70 cut-off reference for electricity (12.8 CO_2/GJ), as defined in the current RED,[93] all potentials from Indonesia and most potentials from Kenya, Brazil are above the limit of GHG emission reduction for heat production, as can be seen in Figure 4.7. When using the proposed 80% reference for electricity (10.7 CO_2/GJ) in the revised RED, 80% of total potentials are not qualified to be exported to the EU. The share of the potentials which does not meet this threshold will not likely be mobilised to the EU in the future if strict GHG emission reductions are applied.

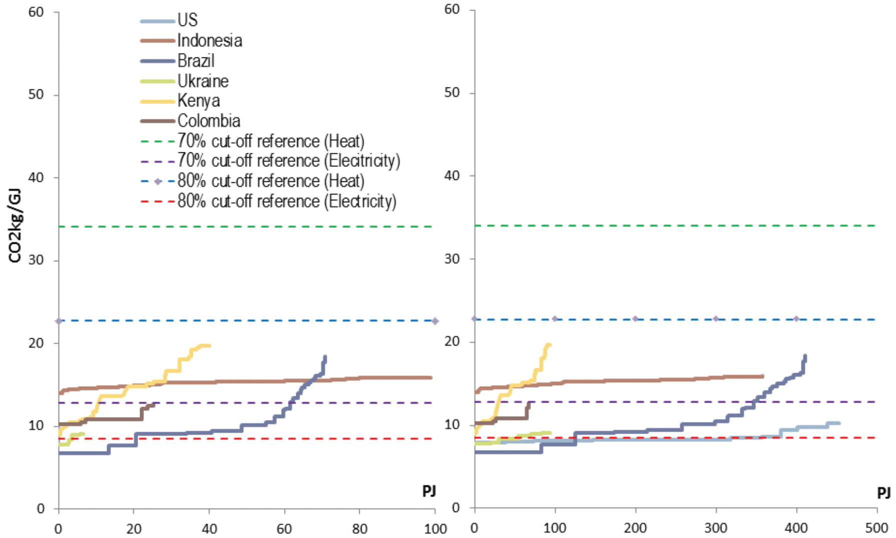


Figure 4.7. Greenhouse gas supply curves of export potential (Brazil, Kenya, Ukraine, United State - solid lines) and sustainable surplus potential (Colombia, Kenya - dashed lines) delivered to the Port of Rotterdam – BAU 2030 (left) & HE 2030 (right)

4.3.6 Sensitivity analysis

- Sustainable surplus potentials:

The uncertainty analysis was based on the sustainable surplus potentials, since this was assessed for all the countries. The export potentials as calculated in this study depend solely on the pelletization capacity as limiting factor and would therefore not show the impact of varying parameters. The three factors that have the highest impact on the sustainable surplus potential, the RPR, the SRF, and the LD were varied in this sensitivity analysis.

For the Ukraine case study, the RPR was varied with the highest and lowest value within Europe,[213] resulting in a variation between 81-137%. For the SRF, a lower value was used based on a EC report, resulting in potentials of 91% of the reference potentials.[213] For the LD, as lower end of the range, the reference value was used combined with the assumption that residues are traded across regions. The higher end of the range uses an alternative estimate from the EC of 14.5% instead of 31%, resulting in a variation between 87-133%.[213]

The RPR variation in Brazil for all crops was modelled after data of the range of Cassava availability, between 144 and 257% of the product.[199] The SRF in Brazil was highly uncertain, as referenced by a variation of corn stover removal in literature between 20% and 100%.[214,215] Alternative sources also provided data on sugarcane tops and straw SRF values of 65% of the reference value and soybean straw SRF values of 144% of the reference values.[216] To reflect this large uncertainty, a variation of 50% for non-process residues was used. The availability of residues varied with 35% based on assumption used by Portugal-Pereira et al.[216]

For the US case study, it was not possible to assess the data uncertainty in literature, since the parameters were the result of several overlapping, spatially explicit datasets. It was not possible to use literature to assess the data uncertainty on this detailed spatial level. Since the pellet production industry is well established in the US, the uncertainty of residue availability as well as the demand for paper, paperboard and panels is considered low. Therefore the RPR and LD were varied with 10%. The SRF was considered somewhat more uncertain, considering the difficulties of determining local sustainability concerns based on a high-level spatial analyses. As a result, the SRF was varied with 25%.

In Colombia, the RPR and SRF values of palm and sugar cane residues were undetermined as residues were estimated based on the total quantity per ha in Colombia. Those values were considered based mainly on the studies of palm residues in Indonesia and Malaysia, with ranges of 82-127% and 74-112% respectively. Local demand was estimated based on the project field interviews with a range of 86-114%.[204]

In Kenya, interviews with representatives of Ministries of Agriculture and Energy as well as meetings with farmers in various regions of the country have resulted in an average RPR range of 82-127%; LD range of 77-136%.[217] Regarding the SRF, no data was available for the Kenyan case study. However, SRF references were taken into considerations from Mozambique and South African data with similar local conditions of agricultural cultivation and harvesting.[79,206,207]

For the Indonesian case study, the average RPR was estimated based on studies of palm oil residue potentials for both Indonesia and Malaysia (of similar climate and agricultural conditions),[218,219] resulting in a variation between 80-124%. Regarding the SRF value, a range of 74-112% was applied based on the studies on palm oil residues used in both Indonesia and Central Kalimantan.[219,220] Based on studies on Malaysian local use of palm residues, the LD was varied between 94% and 115%.[221]

The combined effect of varying the parameters on the potentials in the BAU 2030 and HE 2030 scenarios is shown in Figure 4.8.

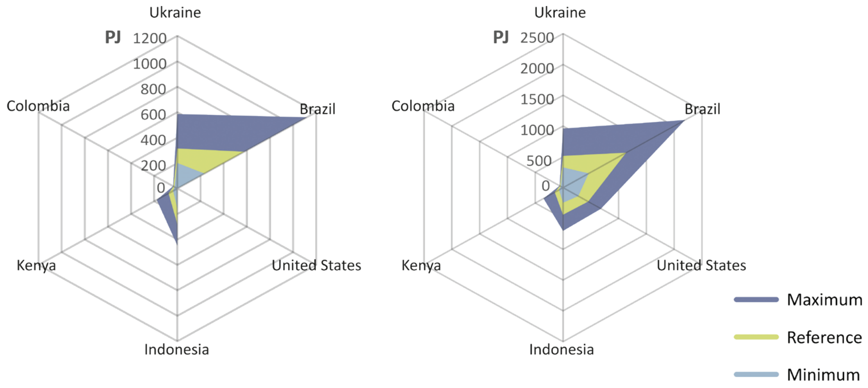


Figure 4.8. Total surplus potential uncertainty ranges of the six case studies – based on the BAU 2030 potentials (left) and HE 2030 potentials (right)

- Costs:

There were large degrees of uncertainty in the use of different cost factors. It was not possible to assess the cost factors through detailed field research in the different case studies or literature review. To show the impact of cost assumption, 5 varying parameters were considered: electricity cost, transport cost (from pre-treatment facilities to import ports), pre-processing cost (including cost of feedstock, collection and transport to pre-treatment facilities), pellet plant capital cost, and labour cost. The cost of electricity was considered relatively less uncertain, and was varied with only 10%. Capital cost of pellet plants was considered the most uncertain, as mentioned in expert interviews, and was varied with 50%. The other factors were varied with 25%.

Figure 4.9 shows the impact of changing different parameters in the different case studies. Colombia was not included since this cost calculation could not be based on country specific parameters. The cost calculation in the US included incremental feedstock cost, resulting in a sharp increase towards the end of the cost supply curve. For the sake of showing the sensitivity to impacts on the largest part of the US cost supply chain, and to align these results with the methodology followed in the other case studies, a cut-off was applied at 15 €/GJ, corresponding to 76% of the total potentials. The results of sensitivity analysis of the different case study countries can be found in Supplementary Information 8.

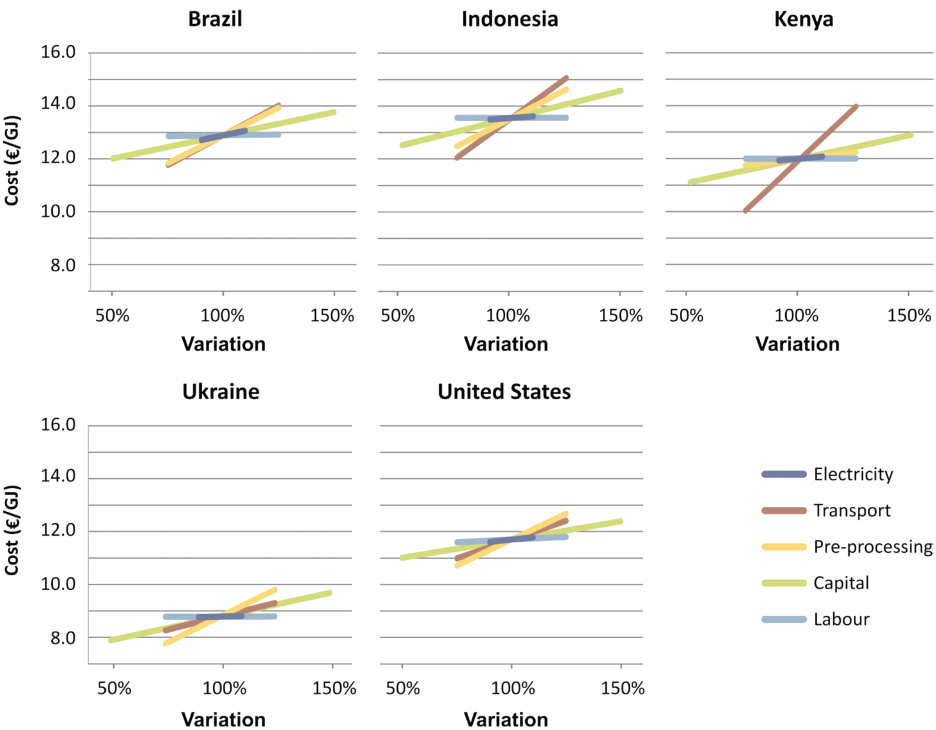


Figure 4.9. Sensitivity of 5 case studies (excluding Colombia) for different cost parameters

The combined effect of varying different parameters (varied with respectively 10%, 25%, and 50% as explained above) is shown as a cost supply curve uncertainty range for the BAU 2030 scenario in Figure 4.10, and for the HE 2030 scenario in Figure 4.11.

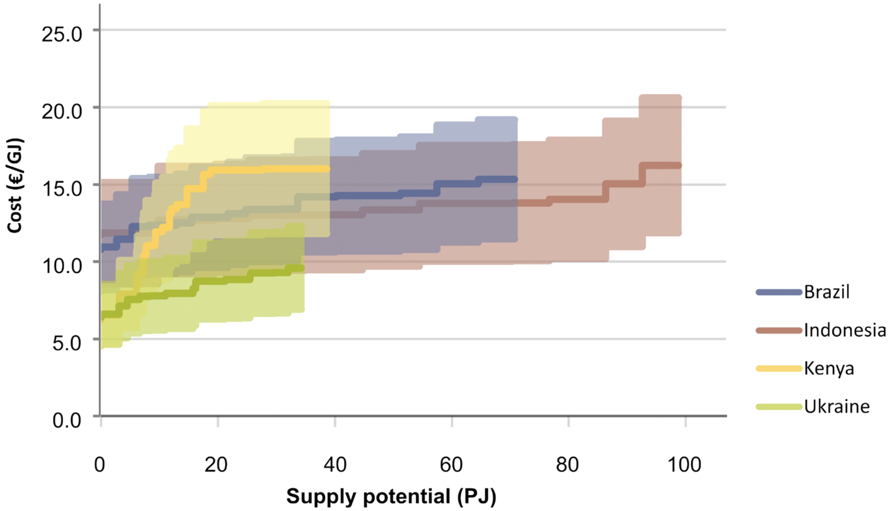


Figure 4.10. Uncertainty ranges cost supply curves – BAU 2030

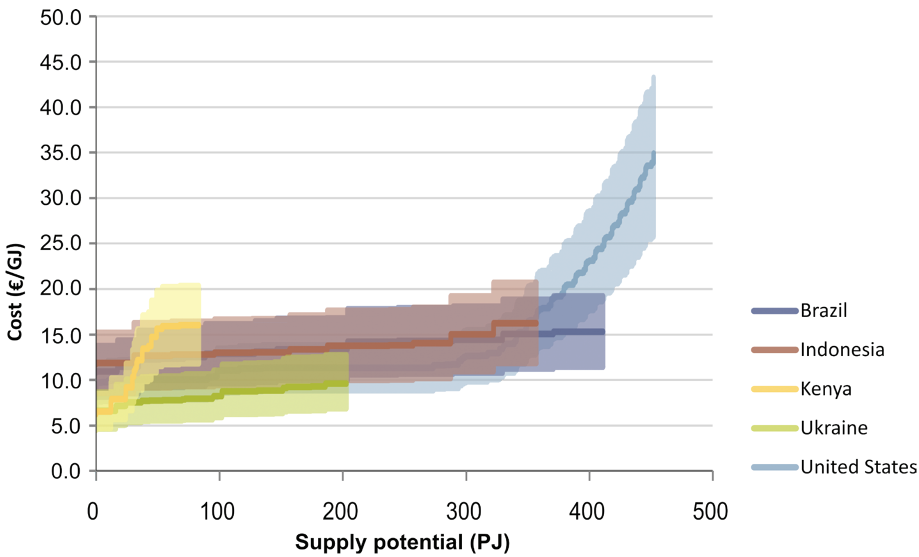


Figure 4.11. Uncertainty ranges cost supply curves – HE 2030

-GHG emissions:

The three key factors impacting the GHG emissions that strongly depend on local conditions are nutrient substitution, transport emissions and electricity production emissions.[33,34,66,67,86–88] Research and consultation with stakeholders were also carried out to investigate to what extent ranges of these factors reflect changes in GHG emissions. The study then considered that in Ukraine, Indonesia, Kenya, Brazil, and Colombia, variation of nutrient substitution and local transport was ± 20% (low: -20% and high: +20%). This can be explained by using nutrients to boost crop yields; and a low quality of infrastructure which results in high GHG emissions per kilometre. Electricity use has a range of ±10% (low: -10% and high: +10%), which reflected changes in electricity use in the sourcing regions. With a similar consideration for local transport in the US, transport emissions were also set at ± 20%. However nutrient substitution is currently not applied for the use of forest biomass in the US, also electricity emission factor is less uncertain, therefore they were set at 5% for comparison and uncertainty analysis.

The results of sensitivity analysis of the different case study countries can be found in S.I.4.1. The combined effects of GHG emissions presented in Figures 4.12, 4.13 and 4.14 show the ranges of total GHG emission uncertainty for the five case studies in the BAU 2030 (no export potentials available for the US under this timeline) and for the six case studies in the HE 2030. In the current situation, the largest part of the export potentials from the sourcing countries meet the EU 80% GHG emission reduction for heat production and 70% GHG emission reduction for electricity production, as can be seen in Figures 4.12, 4.13 and 4.14. Most potentials would be eliminated under the strictest EU GHG emissions limit if three impacting factors are all included (except for some parts from Ukraine, the US and Colombia). Figure 4.14 also indicates that if lower nutrients, less fossil fuels, and grid electricity are used in the local supply chains, a higher quantity of biomass are qualified for export from the Ukraine, the US, and Colombia.

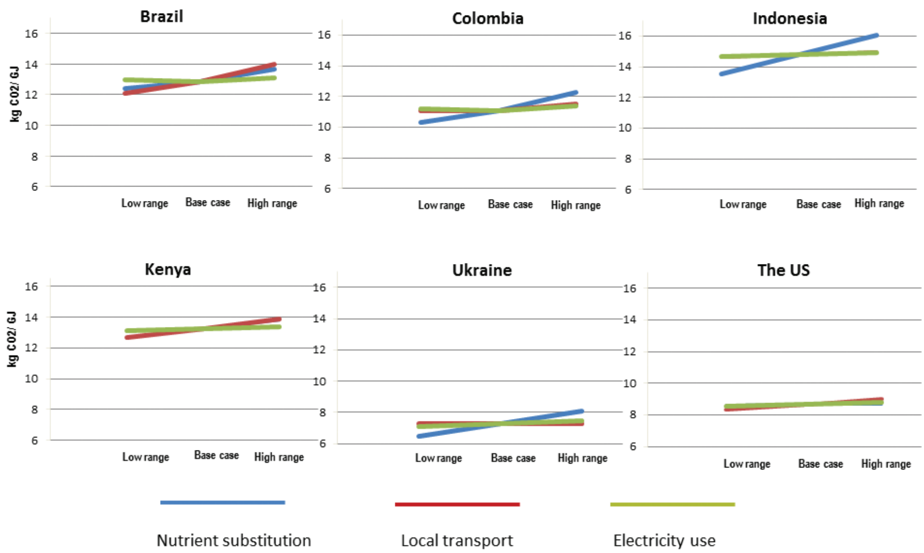


Figure 4.12. Sensitivity of 6 case studies for different GHG emission parameters

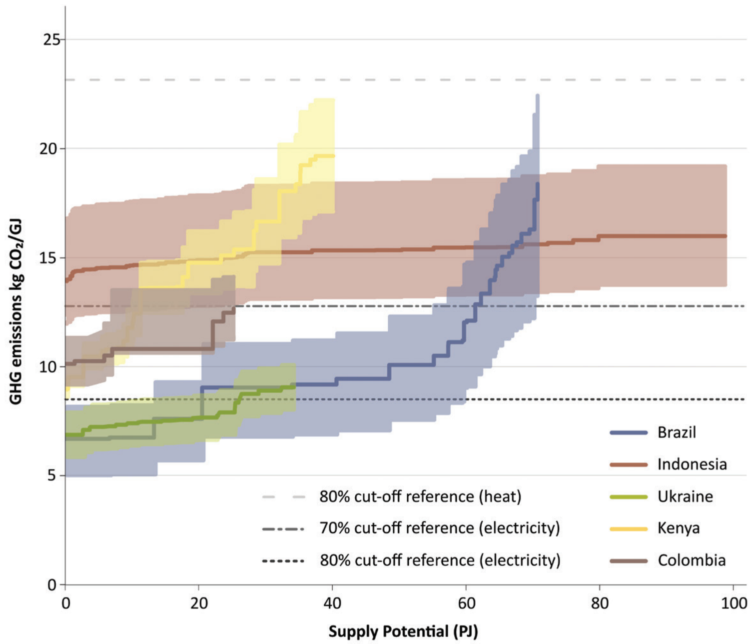


Figure 4.13. Uncertainty ranges GHG emission curves – BAU 2030

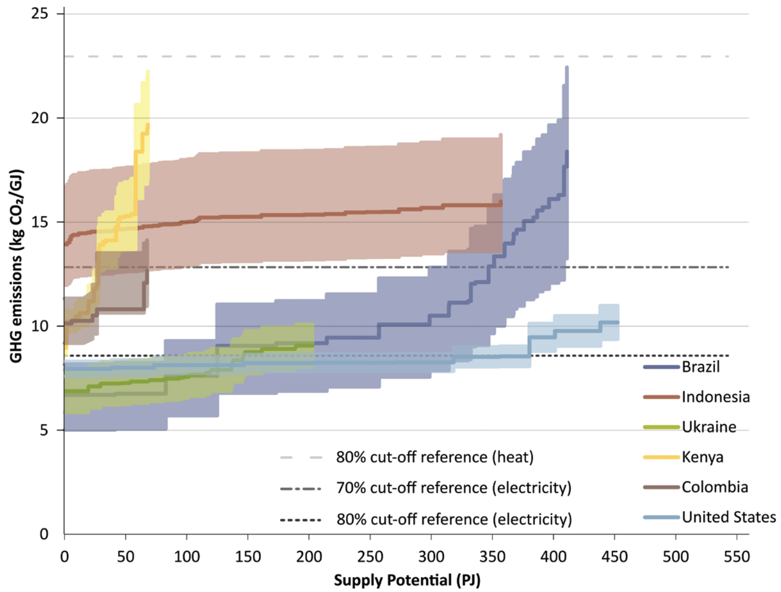


Figure 4.14. Uncertainty ranges GHG emission curves – HE 2030

4.4. DISCUSSION AND CONCLUSIONS

4.4.1 Discussion

- Future export perspective:
In the US, given the interlinkages between the pellet industry and the conventional (in particular sawmilling) wood industry, the pellet industry can only flourish if the traditional industry flourishes.[226] The pellet industry is expected to expand significantly if the conventional forest products use increases, as this would lead to increasing levels of low quality round-wood and residues becoming available. However, these dynamics are not explicitly accounted for in the present analysis. Domestic demand, together with EU sustainability constraints, also plays an important role in determining whether export potentials will be available from the US. In the BAU 2030 case, due to higher local demand and stricter application of sustainability requirements for sustainable biomass exported to the EU, export potentials are equal to zero. In the HE 2030 scenario there is high availability of biomass for export. In order to reach these export quantities, pelletization capacity needs to be expanded, requiring trust by the industry that demand (in the US, the EU or other export markets) will steadily increase.

In Ukraine, forest residues are not included in the potential estimation as in practice they are not mobilized and there are no incentives to change this situation. The quality of the road networks in Ukraine limits accessibility to certain areas, especially during certain weather conditions. This is included in the calculation of cost supply curves in the form of high transport cost per kilometre, but is not included as limiting factor for the calculation of potentials. The lack of pellet plant capacity in the Ukraine strongly limits the export potential. Investments in the bioenergy sector in Ukraine, as a result of increased demand for lignocellulosic biofuels in Europe, could reduce this barrier. However, the current political situation may hinder investments.

In Brazil, potentials increase from the current situation towards 2030. Current agricultural practices of leaving high amount of residues in the field, if positively changed by collecting part of those residues, could add to the surplus potential over time. If the bioenergy sector in Brazil develops, it could make significant contributions to socio-economic developments in Brazil as well as strengthen the renewable energy sector both in Brazil as well as in the EU.

In Colombia, the investigation indicated that more investments in the bioenergy sector would be needed. Calculated potentials are lower than actual potentials as a result of excluding inland regions where transport costs are too high. Investments in accessible infrastructure would increase the potential for lignocellulosic biomass mobilization both for local and export uses. In Indonesia, palm residues such as fronds or empty fruit bunches are currently largely left as waste in the fields and at oil mills. Palm residues are currently free of charge, in the future, feedstock cost might be added once palm residues become commercialised. Costs might also be higher in case the certification of the Roundtable on Sustainable Palm Oil would be implemented to provide sustainability compliance of palm plantation. It was difficult to predict local consumption of palm residues in Indonesia. It is considered likely that palm residues will be largely attributed to export due to the established supply chains of the palm industry. Local households could mobilise other local alternative energy carriers such as rice straw and husk and corn stover.

In Kenya, aggregate biomass potentials decrease over time as food demand, woody biomass deficit, and livestock nutritional needs are projected to increase towards 2030. Some agricultural yields in Sub-Saharan Africa are projected to decrease, caused predominantly by lack of water, soil loss, and land degradation [227]. Proper farming practices could help to boost agricultural production and thereby also result in more residue production. Kenya is not considered a suitable country for energy crop cultivation as many attempts failed to boost biofuel production in the country. There is resistance from local NGOs; there are conflicts between locals, and governmental corruption is an issue. Overall, Kenya does not seem to be a suitable export country until these issues are resolved. This could differ for other Sub Saharan countries. For example, in another study van der Hilst and Batidzirai find substantial biomass export potentials for Mozambique while applying a similar methodology.[78,79]

This study found that, in certain regions, the poor state of infrastructure, logistic conditions and pre-treatment capacity limits the availability of lignocellulosic biomass to be mobilised for export. These barriers furthermore result in high costs and high GHG emissions in some regions. If these challenges are to be overcome, costs and GHG emissions will be reduced and access to feedstocks in remote regions could be achieved, leading to higher export potentials available, with more competitive costs and lower GHG emissions.

If sustainability requirements, are being implemented or established in certain countries, the market price and global trade of lignocellulosic biomass might change from one country to the other. Countries with no or loose sustainability requirements will more likely import certain shares of biomass compared to countries with strict sustainability requirements. More research is necessary to more accurately predict future global trade of lignocellulosic biomass for the bioenergy sectors in different countries.

Differences in local demand for biomass feedstock, sustainability criteria and different levels of market maturity result in different levels of feedstock availability for export. For easy comparison of costs and GHG emissions, the assumption was made that most feedstocks are suitable for pelletization. In reality, agricultural residues may require additional pre-treatment compared to biomass originating from forestry (e.g. washing to remove corrosive elements) or may require pre-treatment through pyrolysis or torrefaction. Those assumptions may also lead to lower or higher biomass availability for export, as well as changed cost supply curves and emissions supply curves.

As a result of limited data availability and difficulties in consulting local stakeholders regarding national policy focus and local markets, results need to be interpreted with a large degree of uncertainty. Market prices for biomass used for bioenergy production were not stable in the last two years and it is difficult to predict market trends in the future.

- Other global demand for biomass:
So far, this paper implicitly assumed that all export potentials are available to the EU. However, the demand for lignocellulosic biomass for bioenergy is predicted to also increase elsewhere until 2030.[149,228] Matzenberger et al.[70] have studied three global integrated assessment models, GFPM, TIMER and POLES, and assessed the (implicit) global biomass trade streams in these models. This study shows that Europe will still be the main importing region of bioenergy by 2030. At the same time there are emerging countries competing for lignocellulosic biomass resources with the EU, notably India, Japan, and Republic of Korea. The latter two have recently started to import biomass for energy. Simply based on the geographic vicinity, it is possible that the Indonesian resource potentials will be used in East Asia rather than be exported to the EU.

While this study has focused on the six case studies, initial investigations of potentials have indicated that countries such as Canada, Russia, Mozambique, Argentina, Vietnam, India and China also have high potentials of lignocellulosic biomass for both local use and export. Canada produces 48 PJ of wood pellets/ year and 90% of this quantity is currently exported. [229,230] Canada also implements sustainable forest management, aiming to meet environmental, socio-economic requirements for lignocellulosic biomass, and is currently a leader in third party certified forests.[230] Russia is an exporting country of wood pellet and has a high potential resulting from its large forest industry,[14,15] although the current political situation has limited its export capacity. According to van der Hilst and Batidzirai.[78,79] Mozambique has potentials of up to 2.7 PJ of combined agricultural and forestry residues as well as potentials of 1.6-7.0 EJ from energy crops. Although local use of food and feed have not been carefully investigated in this study, still Mozambique probably has the potential to export biomass.[78,79,207] Vietnam is currently the leading export of wood pellets to Republic of Korea and Japan with more than 18 PJ of wood pellets exported in the last three years[229], and is currently the highest exporting country of lignocellulosic biomass in Asia.

From this perspective, further investigation in these countries together with this study will provide a more comprehensive overview of potential global trade of lignocellulosic biomass. Given the existence of additional demand for biomass in other world regions and potential additional exporters to the EU not included in this paper, the projected biomass import potentials in this study should be seen as examples to illustrate the order of magnitude and conditions for import, not as lignocellulosic projections.

4.4.2 Conclusions

Results for the six case studies have shown that the sustainable export potential of lignocellulosic biomass is currently limited. However, depending on specific country conditions, the study also shows that sustainable export potentials may increase in the future in most countries, particularly in the HE scenario.

Ukraine, Indonesia and Brazil may become promising sourcing countries in the future as potentials increase from 18, 0 and 9 PJ in the current situation to 203, 356 and 411 PJ respectively in the HE 2030 scenario. On the other hand, potentials in the US decrease to almost zero in 2030 in the BAU scenario when sustainability criteria are applied to the whole forest sector instead of just the pellet sector. Such assumptions were not made in the other case studies. When sustainability criteria are only applied to the pellet sector, the export potentials from the south-east US may become the largest of all case studies, increasing to 452 PJ in the HE 2030 scenario. Potentials in Kenya and Colombia increase only moderately compared to other countries from 20 and 29 PJ in the current situation to 68 and 93 PJ respectively in the HE 2030 scenario.

The feasibility of importing lignocellulosic biomass to the EU is limited by costs. When comparing the estimated costs of lignocellulosic biomass export from the different sourcing countries with the global average market prices in the last five years, it can be seen that this is a main limiting factor. The costs of lignocellulosic biomass from Ukraine are relatively low, ranging from 6.4 €/GJ to 11.8 €/GJ. This can mainly be explained by the shorter transport distance from Ukraine to the port of Rotterdam. Interestingly, Colombia is three times farther from the Netherlands than Ukraine but costs from Columbia are calculated to be between 6.5 and 9.2 €/GJ as a result of cheap feedstock and low pellet production cost. In the US, the costs range between 7.4 €/GJ to 35.0 €/GJ, the high end of the range is the result of increased cost of collecting residues when approaching the maximum potential, resulting in 90% of the potential ranging between 7.4 €/GJ and 15.0 €/GJ and the other 10% ranging between 15 €/GJ to 35.0 €/GJ. As a result of long-distance intercontinental transport, as well as expensive inland transport, Brazil and Indonesia bear higher cost ranges, from 10.8 €/GJ to 15.3 €/GJ and 11.6 €/GJ to 16.2 €/GJ.

The market price of wood pellets in the Netherlands between 2009 and 2016 ranged between 6.3 €/GJ to 8.0 €/GJ, which is considered representative for the international wood pellet market value.[231] It can be seen that lignocellulosic biofuels from the six case study countries are not likely to be exported under the low-end of this price range. Under the high end price, a small potential of 15.7 PJ in the BAU 2030 or 94.4 PJ in the HE 2030 could be exported. In both scenarios this can be attributed to potentials from Ukraine. In all other case studies, calculated supply cost exceed 8.0 €/GJ. If the market price were to increase to 10 €/GJ, the import potential meeting this threshold would increase to 34.2 PJ in the BAU 2030 scenario and 308 PJ in the HE 2030 scenario.

This study also shows that GHG emissions are currently not a critical issue in the investigated countries for biomass to be qualified for export to the EU. The entire potentials from all the six investigated countries comply with the GHG reduction requirements of 70% reduction compared to fossil fuel based electricity production, as defined in the proposed RED.[222] This can be explained by the fact that the largest part of the potentials is mobilized from agricultural and forest residues where emissions from cultivation are exempted. In addition, pre-treatment plants partly use lignocellulosic biomass to produce electricity for their operations. Therefore, pre-treatment emissions are also partly exempted.

If the requirements of GHG emissions are strengthened up to an 80% reduction, as identified in the proposed RED,[93] only the potentials in the US, Ukraine and Colombia, and part of the potentials in Kenya and Brazil, meet the sustainability requirements for heat production. The potentials are particularly limited regarding biomass used for heat production, in this case only part of the potentials from the US, Ukraine and Brazil meet the reduction criterion. This is mainly due to intercontinental and local transport which accounts for a large share of the GHG emissions, especially from countries far away from the European Union. In Indonesia, Ukraine and Kenya, high amounts of fertilisers need to be used for nutrient substitution, which also causes higher total emissions.

Despite all these constraints, it can be concluded that substantial sustainable biomass export potentials currently exist, and one of the biggest constraints is currently to mobilise these potentials. The results presented in this study were used in the Bio-Sustain study, research at EU level to analyse potential future intra-EU and extra-EU biomass supply scenarios. The BioSustain results show that the potential from the case studies included in the Biotrade2020+ study could cover 32% of the extra-EU demand for biomass in 2020 and 69% in 2030.[232]

SUPPLEMENTARY INFORMATION

S.I.4.1 Classification of feedstocks

Agricultural resources	
Primary	Crop residues from major crops – corn stover, small grain straw, and others Grains (corn and soybeans) used for ethanol, biodiesel, and bio products Perennial grasses Perennial woody crops
Secondary	Animal manures Food/feed processing residues
Tertiary	Municipal solid waste and post-consumer residues and landfill gases
Forest resources	
Primary	Logging residues from conventional harvest operations and residues from forest management and land clearing operations Removal of excess biomass (fuel treatments) from
Secondary	Primary wood processing mill residues Secondary wood processing mill residues Pulping liquors (black liquor)
Tertiary	Urban wood residues – construction and demolition debris, tree trimmings, packaging wastes and consumer durables

S.I.4.2 RPR & LHV values & SRF

	Feedstock	RPR (t/t)	LHV (MJ/kg) (%)	SRF (%)
Brazil	Sugarcane tops/straw	0.34[233]	17.38[234]	50[i]
	Sugarcane bagasse	0.30[233]	17.71[235]	100[236]
	Soybean straw	1.40[233]	12.38[235]	25[237]
	Corn stalk	0.78[238]	17.45[i]	30[237,239,240]
	Corn cob	0.22[199]	16.28[23]6	30[237,240–242]
	Corn husk	0.20[236]	12.00[235]	30[237,240–242]
	Cassava straw	0.80[233]	17.50[235]	30[237,240–242]
	Rice straw	1.48[233]	16.02[235]	25[237]
	Rice husk	0.22[233]	14.17[243]	100
	Coffee husk	0.21[233]	17.71[234]	100
	Orange peel	0.50[244]	17.11[245]	100
	Field residues	0.15[246,247]	19.05[248]	52,5[249]
	Paper and cellulose production residues	0.117[240,241]	18.18[242]	100
	Sawmill and furniture industry residues	0.3825[199,243,250]	18.18[245]	100

		RPR (t/t)	HHV (MJ/kg)	SRF (%)[251]
Colombia	Sugarcane trash	3.26[252]	18.69[253]	50-70[ii]
	Oil palm shell	0.22[25]4	21.5[255]	83-92[iii]
	Oil palm fibre	0.63[252]	19.2[255]	83-92[iii]
	Oil palm empty fruit bunch	1.06[252]	17.9[255]	83-92[iii]
	Sugarcane bagasse	2.68[252]	19.37[253]	100
Indonesia		**RPR (%)[218,221]**	**LHV (MJ/kg)[218]**	**SRF (%)[218,221]**
	Palm EFB	21.07	18.88	95
	Palm shell	4.29	20.09	85
	Palm fibre	15.42	19.06	85
		Dry quantity(t/ha)		
	Palm frond	10.88	15.72	100
	Palm trunk	2.48	17.47	100
		RPR (t/t)[206,208,256–258]	**LHV (MJ/kg)[206,218,259–261]**	**SRF (%)[206,218,259–261]**
Kenya	Bagasse	0.38	12.93	40
	Sugarcane stalks & leaves	0.22	16.61	9
	Molasses	0.04	8.50	100
	Sisal ball	4.10[iv]	14.85	83 [iv]
	Sisal bogas	19.80[v]	14.85	100 [v]
	Coffee husk	0.24[vi]	14.10	83 [vi]
	Coffee pulp	2.42[vi]	0.01	100 [vi]
	Coconut husk	1.10	17.66	100
	Rice straw	2.19	13.45	3
	Rice husk	0.29	16.17	100
	Off-cuts & chips (share in timber waste)	57,5%[207,262]	19.2[252,263–265]	81
	Sawdust (share in timber waste)	19,5%[vii, 207]	16.8[252,262–264]	0
		RPR (t/t)	**LHV (MJ/kg)**	**SRF (%)[vii]**
Ukraine	Barley	0.8	13.6[266] (wet)	0 – 100
	Maize	1.3	7.6[266]	0 – 100
	Rapeseed	1.8	14.3[266]	0 – 100
	Sunflower	1.9	5.7[266]	0 – 100
	Wheat	1	13.3[266]	0 – 100
	Primary forestry residues		16.0	0 – 75
	Secondary forestry residues		17.9	0 – 75

		RPR	LHV (MJ/kg, wet)	SRF (%)[211]
United States	Mill residue	[viii]	6.95	100
	Logging residue	[viii]	6.95	50 – 67[ii]
	Softwood biomass	[viii]	6.95	[ix]
	Hardwood biomass	[viii]	6.95	[ix]
	Other removals	[viii]	6.95	50

i. A. Roozen, personal communication
ii. Varies per scenario.
iii. Varies per scenario, total for oil palm residues (including empty fruit bunch, fiber and shell).
iv. This price is calculated based on data from Real Vipingo sisal estate in Kilifi County. Per year 300 ha is harvested, per ha 3000 plants are produced, with a sisal ball weighing 20 kg. Fiber production was 5,100 t in 2014.
v. The lower limit of sisal bogas RPR is provided by Real Vipingo's estate measurements.
vi. Data from Kofinaf (coffee mill) in Kiambu County.
vii. Varies per region in Ukraine, calculated using spatial data on soil type, production intensity, crop type and climate.
viii. Calculated using spatial date on forest product removal (on county level) form the US Forest Service Timber Products Output (TPO) database (USDA-USFS 2015).
ix. Varies per region in the US, calculated using spatial data on protected areas of conservation significance, rarity-weighted species richness and forest types (taking into account exclusion of gum-cypress and a 10% exclusion of oak-pine forest types).[267]

S.I.4.3 Local demand

(share not available) (%)

		Current	2020 BAU	2020 HE	2030 BAU	2030 HE
Brazil	Sugarcane bagasse	90	100	90	100	90
	Sugarcane tops/straw	0	0	0	50	25
	Soybeans straw	0	10	0	30	0
	Corn stover	60	60	50	60	30
	Cassava straw	100	100	100	100	100
	Rice straw	0	0	0	0	0
	Rice husk	75	85	67	100	67
	Coffee husk	100	100	100	100	100
	Oranges peel	100	100	100	100	100
	Forestry field		0-15	0-5	0-40	0-25
	Paper & cellulose production		75	70	85	70
	Lumber processing		75	70	85	70
Ukraine	Combined residues (straw)	31	31	15.5	31	15.5
Colombia	Sugar cane trash	0	5	10	20	10
	Palm EFB	36	10	15	10	15
	Palm shell	9	3	10	5	10
	Palm fibre	25	2	10	5	10
Indonesia	Palm frond	0	0	10	10	15
	Palm trunk	0	0	10	10	15
	Palm EFB	10	10	15	15	20
	Palm shell	10	10	15	15	20
	Palm fibre	10	10	10	15	20
Kenya	Bagasse	0	0	0	0	0
	Sugarcane stalks & leaves	6	4	4	6	6
	Molasses	50	50	50	50	50
	Sisal ball	0	0	0	0	0
	Sisal bogas	0	0	0	0	0
	Coffee husk	100	100	100	100	100
	Coffee pulp	100	100	100	100	100
	Coconut husk	17	16	16	16	16
	Rice straw	0	0	0	0	0
	Rice husk	7	5	5	7	7

	Off-cuts & chips (share in timber waste)	21	18	18	21	21
	Sawdust (share in timber waste)	100	100	100	100	100
US	Forest biomass	69	73	63	76	57

S.I.4.4 Cost factors & country specific cost factors

			Brazil	**Colombia**[i]	**Kenya**	**Indonesia**	**Ukraine**	**United States**
Feed-stock	Moisture content (fresh)	%	50%	50%	50	73	50%	50%
	Moisture content (dry)	%	8.5%	8.5%	8.5	7	8.5%	8.5%
	Cal. Value after drying	MJ / kg ar (LHV)	16.35	16.35	16	16.35	16	16
	Interest rate (IRR)		10%		10	10	10%	10%
Pellet plant	Scale	MT/year	120,000			120,000	120,000	120,000
	Operating hours	h/year	7,000			7,000	7,000	7,000
	Electricity price	€ /MWh	121.9		49.6	73.4	14.5	60.0
	Labour	€ /h	8.1		0.5	1.1	1.8	25.0
	Heat source		Biomass	Biomass	Biomass	Biomass	Biomass	Biomass
	Pelletizing cost	€/t	58.9	50	55.9	79.4	58.9	107.9
Transport	Distance to pellet plant	km	50		110	55	[i]	i
	Transport cost (truck)	€ /km/t	0.09	0.08	0.16	0.42	[i]	0.071[ii]
	Truck loading			1.50				
	Transport cost (train)	€ /km/t			0.16	-	[i]	0.03
	Harbor cost	€ /t	7.26	21.50	1.46	0.37	[i]	[i]
	Ocean cost			15 / 20				
	Profit	%	10%		10	10	10%	10%
Agri residues	Field processing	€ /t field site	12.1	21.25/32.3[iii]	2.04	3.36	12.1	-
Forest residues	Field processing	€ /t field site	20.0		2.04	-	20.0	[iv]
Energy crops	Field processing	€ /t field site	12.1			-	12.1	-

i. For these two countries, it was possible to calculate the transport cost in more detail by making use of the existing BIT-UU model 136. In the case of Ukraine, transport cost from any point in the Ukraine until the Port of Rotterdam could be calculated. In the case of the US, the BIT-UU model included transport cost from several export ports to the Port of Rotterdam. Calculated based on 137, with time cost and variable cost taken from data about trucks in the EU.
ii. Biomass cost, including cleaning of trash.
iii. Cost are taken from the Billion Ton Update.[77] This study reports increasing production costs with increased mobilization of biomass. This is considered more realistic in a well-developed market such as the US.

S.I.4.5 Included states Brazil case study

S.I.4.6 National electricity emission coefficients

Country	Electricity emission coefficient gCO2-eq/MJ[268]
United States	180
Ukraine	167
Colombia	45
Brazil	31
Indonesia	296
Kenya	81

S.I.4.7 Other emissions factors

Nutrient substitution - emission factor chemicals[222]					
Fertilizer		CO2	CH4	N2O	CO2-eq.
N	kg/t	2,670.87	6.94	2.10	0
P2O5	kg/t	1,459.04	3.73	0.00	0
K2O	kg/t	409.20	0.17	0.00	0
Pesticides	kg/t	6,650.33	10.03	1.68	7,402.33
Pre-treatment[222]					
		CO2	CH4	N2O	CO2-eq.
Cultivation	g/MJ wood pellets	0.842	0.0000088	0.0000368	0.85
Chipping	g/MJ wood pellets	0.248	0.0000026	0.0000109	0.25
Drying	g/MJ wood pellets	0.070	0.0000007	0.0000031	0.07
Pellet Mill	g/MJ wood pellets	0.146	0.0000015	0.0000064	0.15
Pellet Mill	MJ/MJ wood pellets	0.050			

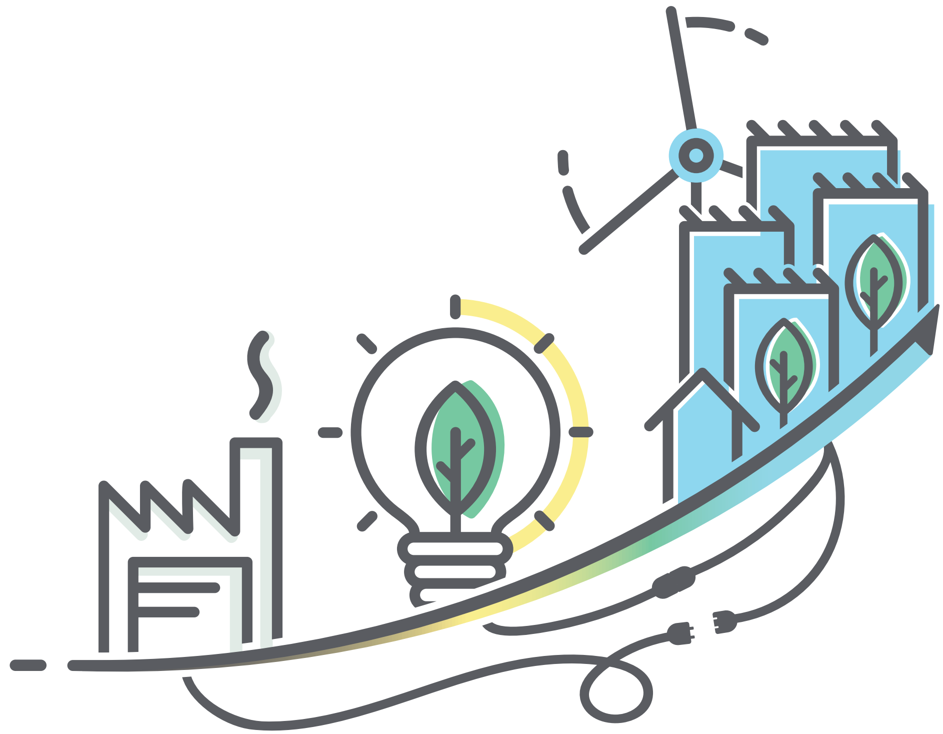
S.I.4.8 Impacting factors to total supply chain costs (in €/GJ)

Country	Impacting factor	50%	75%	90%	100%	110%	125%	150%
Brazil	Electricity			12.7	**12.9**	13.1		
	Transport		11.8	12.4	**12.9**	13.3	14.0	
	Pre-processing		11.8	12.5	**12.9**	13.3	13.9	
	Capital	12.0	12.4	12.7	**12.9**	13.1	13.3	13.8
	Labour		12.9	12.9	**12.9**	12.9	12.9	
Indonesia	Electricity			13.5	**13.6**	13.6		
	Transport		12.0	13.0	**13.6**	14.2	15.1	
	Pre-processing		12.5	13.1	**13.6**	14.0	14.6	
	Capital	12.5	13.0	13.3	**13.6**	13.8	14.1	14.6
	Labour		13.5	13.6	**13.6**	13.6	13.6	
Kenya	Electricity			11.9	**12.0**	12.1		
	Transport		10.0	11.2	**12.0**	12.8	14.0	
	Pre-processing		11.8	11.9	**12.0**	12.1	12.3	
	Capital	11.1	11.6	11.8	**12.0**	12.2	12.4	12.9
	Labour		12.0	12.0	**12.0**	12.0	12.0	
Ukraine	Electricity			8.8	**8.8**	8.8		
	Transport		8.3	8.6	**8.8**	9.0	9.3	
	Pre-processing		7.8	8.4	**8.8**	9.2	9.8	
	Capital	7.9	8.3	8.6	**8.8**	9.0	9.2	9.7
	Labour		8.8	8.8	**8.8**	8.8	8.8	

The US	Electricity			11.6	**11.7**	11.8		
	Transport		11.0	11.4	**11.7**	12.0	12.4	
	Pre-processing		10.7	11.3	**11.7**	12.1	12.7	
	Capital	11.0	11.4	11.6	**11.7**	11.8	12.0	12.4
	Labour		11.6	11.7	**11.7**	11.7	11.8	

S.I.4.9 Impacting factors to total supply chain costs (in €/GJ)

Country	Impacting factor	Low range	Base case	High range
Brazil	Nutrient substitution	12.4	**12.9**	13.7
	Local Transport	12.1	**12.9**	14.0
	Electricity	13.0	**12.9**	13.1
Colombia	Nutrient substitution	10.3	**11.1**	12.3
	Local Transport	11.1	**11.1**	11.5
	Electricity	11.2	**11.1**	11.4
Indonesia	Nutrient substitution	13.5	**14.8**	16.1
	Local Transport	14.6	**14.8**	15.0
	Electricity	14.7	**14.8**	14.9
Kenya	Nutrient substitution	12.7	**13.3**	13.8
	Local Transport	12.7	**13.3**	13.9
	Electricity	13.2	**13.3**	13.4
Ukraine	Nutrient substitution	6.5	**7.3**	8.1
	Local Transport	7.3	**7.3**	7.3
	Electricity	7.1	**7.3**	7.5
The US	Nutrient substitution	8.6	**8.7**	8.7
	Local Transport	8.3	**8.7**	9.0
	Electricity	8.5	**8.7**	8.8



5

Effective sustainability criteria for bio-energy: Towards the implementation of the European Renewable Directive II

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5.1 INTRODUCTION

5.1.1 Bioenergy development in the European Union

Renewable energy, including bioenergy, plays an important role in the European Union (EU) in improving energy supply security by reducing the EU's dependence on (imported) fossil fuels, making energy supply more sustainable, and mitigating climate change.[8,269–271] Since 2001, renewable energy policies have stimulated the rapid development of bioenergy in the EU. Gross inland consumption of bioenergy increased from 2,320 PJ in 2000 to 5,880 PJ in 2017.[57] Today, bioenergy accounts for 64% of gross inland consumption of renewable energy, and it is expected to remain the largest source of renewable energy for the coming decade.[57]

The development of bioenergy in the past decade was shaped largely by the targets set in the Renewable Energy Directive 2009/28/EC (RED I). The RED I established binding specific national targets for renewable energy to be met by 2020: a contribution of 20% to the total final energy supply in the EU, and of at least 10% to the transport sector in each Member State (MS). In 2018, the revised Renewable Energy Directive Recast (RED II) was adopted,[272] succeeding the RED I in promoting the use of renewable energy in the EU for the period 2021-2030. It sets a new binding renewable energy target for 2030 of at least 32% of the gross final energy consumption and a sub-target of renewable energy supply in transport of at least 14%. To meet these targets, bioenergy consumption is projected to increase to 8.0 EJ by 2030. Scenarios aimed at meeting the climate target as agreed in the Paris Agreement show that beyond 2030, bioenergy will still contribute significantly to the renewable energy supply, ranging between 8.0 and 10.5 EJ by 2050.[271] In the Paris Climate Agreement, the EU committed to reducing the greenhouse gas (GHG) emissions and to limiting the increase in temperature to well below 2 degrees Celsius. The increased consumption of bioenergy will enhance the EU's efforts to move towards a low carbon economy by 2050.[271]

5.1.2 European sustainability framework for bioenergy and pending issues

Early development of bioenergy policies to guarantee sustainability
Along the development of bioenergy in the past few decades, the growth of liquid biofuels produced from food-based crops has led to concerns over possible impacts

on agricultural food production and land use change.[273] In response to these impacts, biofuels used in transport and bioliquids used in electricity, heating and cooling must comply with EU-wide binding sustainability criteria.[91] Sustainability compliance of biofuels and bioliquids needs to be verified either through national legislations or through voluntary schemes that are recognised by the European Commission (EC). The sustainability criteria are part of a larger sustainability framework, partly also regulated in the EU through the environmental cross-compliance requirements in the Common Agricultural Policy (CAP) and in the national forest management programme guided by the EU Forestry Strategy.[111] The volume of certified biofuels in total transport renewable energy in the EU has increased as a result of the implementation of the RED I's sustainability criteria (see Figure 5.1).

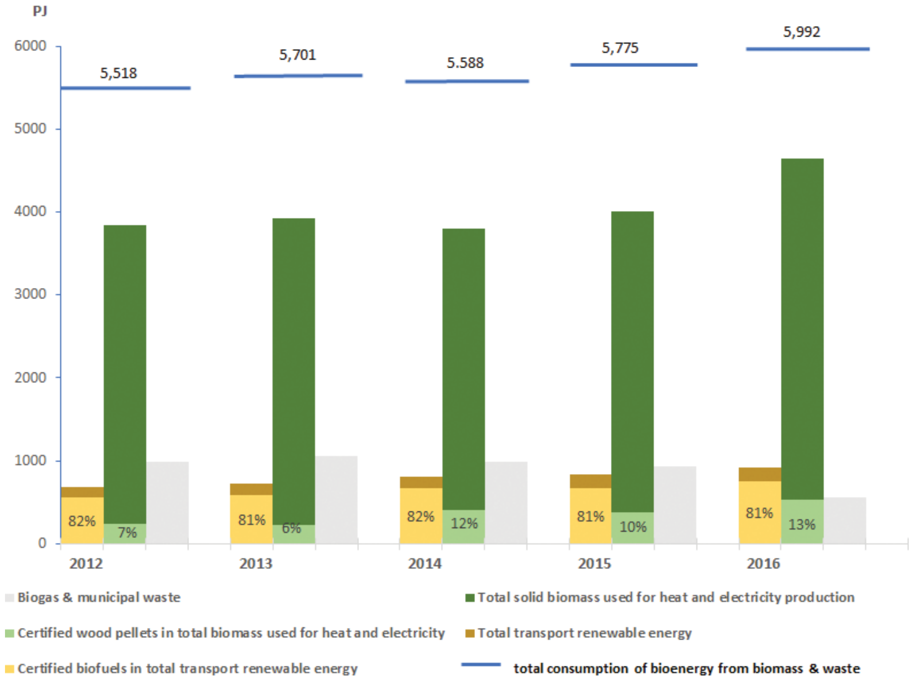


Figure 5.1. Sustainably certified biofuels in transport and the share of sustainably certified solid biomass in total solid biomass used for heat and electricity in the EU. The amount of certified biogas is unknown. Municipal solid waste is not certified. Based on sources: [11, 12, 13]

Sustainability risks were considered low for solid and gaseous biomass used for bio-energy. Domestic biomass that originates from waste and residues, agricultural, and forestry residues was deemed unlikely to trigger direct or indirect land use change.

However, to further respond to sustainability concerns and avoid negative sustainability impacts, the EC encouraged its MSs to develop national sustainability criteria for solid biomass, addressing land use, land use change, and forestry (LULUCF) and minimum GHG emission savings.[92,111] Some flexibility was given to MSs as it was difficult to establish EU-wide sustainability criteria for solid biomass: different feedstocks are used in different MSs, which presents challenges for consistent sustainability compliance. MSs were advised to translate sustainability criteria into their own legislation, following the criteria applying to biofuels.[111]

EU binding sustainability criteria for all bioenergy sectors

International biomass trade of both liquid biofuels and solid biomass has grown substantially in the past two decades.[274] The main importing countries, including the United Kingdom (UK), Belgium, the Netherlands, and Denmark have adopted sustainability criteria for solid biomass at the national level. These sustainability criteria were established to ensure GHG emissions savings whilst assuring that solid biomass is produced in a sustainable way, and sustainability impacts in the sourcing countries outside the EU are avoided.[72,85] With the implementation of these national criteria, the volume of certified solid biomass has increased gradually in the whole EU, from 3% in 2012 to 10% of total solid biomass used for heat and electricity in 2016 (see Figure 1). However, some concerns still exist. On the one hand, it has been shown that not all types of biomass are instantaneously carbon-neutral[275]; moreover, risks of negative impacts of biomass to biodiversity, soil, water, and land use remain.[94,95,276] On the other hand, it creates an administrative burden to prove comprehensive sustainability compliance with divergent national regulations and initiatives. Proof of compliance to these divergent systems has been shown to be a barrier to international and intra-EU trade in solid biomass fuels, thus making it more difficult or costly to meet increasing biomass demand.[277]

In 2018, the RED II was adopted, aiming to minimise these concerns, to avoid environmental impacts and market distortions, to promote resource efficiency, and to safeguard both proportionality and cost-effectiveness (by applying risk-based approach and thresholds for bioheat and power plants). The RED II establishes binding environmental criteria for large plants (with a total rated thermal input equal to or exceeding 2 MW for gaseous biomass fuels and 20 MW for solid biomass fuels). In fact, the RED II allows MSs to establish stricter and/ or additional sustainability criteria for solid biomass. The transposition to the national level needs to be completed by the end of 2020.

Studies assessing sustainability criteria defined in the proposed RED II[144] (which are almost identical in the final version of the RED II) found that unclear definitions of some sustainability criteria are used. The studies also showed the risk of unsustainable mobilisation of feedstocks for bioenergy production[87,88]; and they identified some loopholes to iLUC prevention.[89] Given this context, it may be challenging to transpose the RED II's guidance into national legislations to assure sustainability compliance. The updated and new sustainability criteria defined in RED II may add more complexity for policy makers, voluntary scheme owners, certification bodies and auditors involved in sustainability certification. Furthermore, sustainability criteria have been implemented separately in many voluntary schemes and national legislations.[132,278,279] There may be lessons to be learned for stakeholders from the establishment and verification of sustainability criteria in those systems for the promotion of sustainable bioenergy at the MS level.

5.1.3 Objectives

This study aims to address pending sustainability issues of the RED II and proposes efficient sustainability criteria to assure sustainability compliance for the whole bioenergy sector. In detail, the study:

- reviews sustainability criteria defined in RED II and identifies possible gaps in sustainability compliance
- reviews sustainability criteria established in voluntary schemes and national legislations for biofuels and solid biomass, and investigates to what extent they meet the RED II's sustainability criteria
- proposes effective sustainability criteria which respond to sustainability concerns and which can actually be implemented in practice
- provides recommendations based on best practices to policy makers, voluntary scheme owners, certification bodies and auditors involved in sustainability certification and sustainability practitioners on the establishment and implementation of sustainability criteria for bioenergy in the long term.

5.2 METHOD

The methodology of this study involved five steps (see Figure 5.2). The first step consisted of a review of sustainability criteria and sustainability verification as defined in the RED I and RED II. The second step was to review national legislations and voluntary schemes designed to verify bioenergy sustainability in some MSs and at EU level. In addition, in this step the similarities and differences among those systems were identified, and it was revealed which systems include a comprehensive set of sustainability criteria that go beyond RED II's definitions. Based on the findings in the first two steps, the third step proposed effective sustainability criteria for the whole bioenergy sector. The fourth step comprised a consultation with industrial stakeholders, policy makers and relevant experts. The consultation was carried out via an online survey and interviews. A questionnaire was developed and sent to a number of selected stakeholders in order to (1) validate the effective sustainability criteria for bioenergy; (2) investigate the updates of sustainability frameworks in the MSs, and (3) receive their opinions and vision on the adoption of the RED II and its transposition to national legislations. The questionnaire was also published online to elicit additional input from dedicated stakeholders. The final step included a review of the three aforementioned parts, presented the results of assessing sustainability criteria in various systems, and ultimately re-affirmed the set of effective sustainability criteria. It also provided recommendations on the establishment and implementation of sustainability criteria for bioenergy.

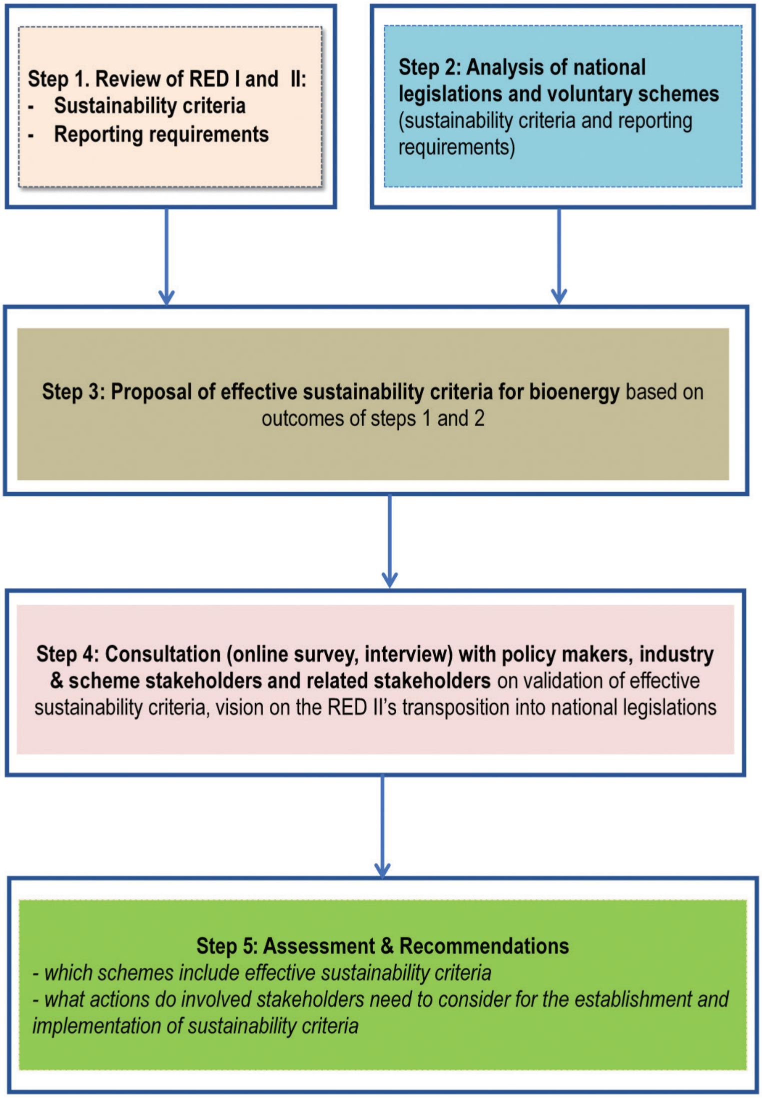


Figure 5.2. Method to assess sustainability criteria for bioenergy

In this article, we identified and discussed effective sustainability criteria. We defined effective sustainability criteria as criteria that are considered relevant and applicable in practice. These criteria have been recognised and/or approved by stakeholders who are involved in the development, implementation and monitoring of bioenergy sustainability. We also assessed the sustainability criteria defined in the RED II, national legislations and voluntary schemes; in other words, stringent and comprehensive sustainability criteria were also considered.

To support the discussion on sustainability criteria which are established in MSs and in voluntary schemes, we have defined some terminology below with the help of the Oxford Dictionary and Allen et al.[280]

- ***Stringent sustainability criteria*** *are sustainability criteria which are clearly defined without misinterpretation from stakeholders*
- ***Comprehensive sustainability criteria*** *are sustainability criteria which take into account a wide range of indicators to assure sustainability compliance*
- ***Efficient sustainability criteria*** *are sustainability criteria established in voluntary schemes or national legislations of potentially mutual recognition aiming to achieve maximum productivity with minimum administrative burdens and costs.*

Other terminology regarding bioenergy types and voluntary schemes is provided in S.I.5.1.

5.3 REVIEW OF THE RED II

5.3.1 Overview of sustainability criteria in the RED II

Compared to the RED I's criteria, some binding sustainability criteria for biofuels remain unchanged. The RED II introduces new sustainability criteria for biomass supply from forest and agriculture which are independent of its end use (such as biofuels, electricity, and heat). The new aspects for biomass feedstocks include LULUCF and the risk of minimisation of unsustainable production, options for sustainability compliance, and avoidance of land use impacts for forest biomass. The RED II requires higher GHG emission savings for the supply chains, which is the only criterion that is dependent on its end-use. Waste and residues only have to comply with the GHG saving requirement, but monitoring of soil quality and solid carbon is required for agricultural waste and residues. To address GHG emissions from iLUC, the ILUC Directive has established guidelines to measure low iLUC risks.[281] The RED II adds national limits for high iLUC-risk biofuels, bioliquids and biomass fuels (produced from food or feed crops for which a significant expansion of the production area into land with high carbon stock is observed): they should remain at MS 2019 levels for the period 2021-2023, and then gradually decrease to zero by 2030.

Table 5.1 presents an overview of the sustainability criteria defined in the RED I and the RED II.

Table 5.1. Sustainability focuses for bioenergy defined in the RED I and RED II

Binding sustainability focus		***RED I***	***RED II***
Environmental criteria:			
1	*Waste & residues*	need to fulfil GHG emissions savings	need to fulfil GHG emissions savings and address impacts on soil quality and soil organic carbon
2	*GHG emissions savings*	at least 35% and 60% savings for waste and residues and for biofuels produced in installations started on or after 1 January 2017, respectively	at least 65% for biofuels, biogas consumed in the transport sector, and bioliquids produced in installations in operation from 1 January 2021; 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.
3	*No production from land with high biodiversity value*	applied to biofuels	applied to biofuels, bioliquids and biomass fuels produced from agricultural biomass
4	*No production from land with high carbon stock*		Same as for (3)
5	*No production from peatland as of January 2008*	No change from RED I to RED II	
6	*Risk minimisation of unsustainable production*	X	national or sub-national laws applicable for harvesting, monitoring, enforcement systems of forest biomass; or seek similar risk mitigation/management systems
Socio- economic criteria:			
		Not established	
Verification of sustainability compliance:			
7	*Land use, land use change and forestry*	X	provide evidence or seek management systems to ensure that carbon stock and sink levels in the forest are maintained, or strengthened over the long term
8	*Mass balance*	allows consignments of raw material or biofuel with different sustainability characteristics to be mixed	clarifies further detailed information on how to measure and report mass balance

5.3.2 Reflection on the RED II's sustainability criteria

Some studies recently identified certain remaining sustainability gaps given the sustainability criteria established in the RED II. Regarding the criteria of risk minimisation of unsustainable production for forest biomass, the RED II allows the use of biomass from primary forests as long as it meets sustainability criteria.[87,88] This has already been disapproved of by environmental non-governmental-organisations (NGOs) due to the risk of depleting carbon stocks.[95] Socio-economic criteria are excluded in the RED II, but they are regarded as important for ensuring credible sustainability compliance.[282,283] For comparison, some common socio-economic criteria for biomass feedstocks, including labour rights, land rights, and food security, have been implemented in a number of voluntary schemes.[282–284] Some studies also indicated possible socio-economic conflicts in international sourcing regions as compliance with national and regional regulations is not easily verified.[85,86] The importance of resource-efficient use of biomass, such as waste hierarchy or cascading use of biomass, which is absent in the RED II, has also been raised by several studies.[285–287] Resource efficiency of biomass was considered important to maximise the cost effectiveness, minimise waste and avoid negative impacts on the environment.

5.3.3 Verification and certification of bioenergy sustainability

Regarding the sustainability certification and verification defined in the RED II, certain concerns from the implementation of the RED I still remain. Some studies showed that there are large differences between voluntary schemes recognised by the EC used to certify biofuels, not only regarding the content and strictness of criteria, but also regarding their level of assurance.[81,288] The schemes involve various stakeholder groups on setting standards and verification, such as Better Biomass and Roundtable on Sustainable Biomaterials (RSB), and they provide a higher level of sustainability performance.[288]. Scientific experts, exploring a more holistic understanding of sustainability, also indicated a number of specific gaps which are not sufficiently addressed in many voluntary schemes[86], namely resource efficiency, iLUC, risks of negative impacts on food prices and supply, and soil organic carbon.

Some studies also suggested that the establishment of sustainability criteria should consider not only various environmental, socio-economic aspects but also practicality of application.[95,280,284,289,290] In addition, the establishment of relevant sustainability criteria helps to gain social acceptance for bioenergy development.[64,291]

Based on our review of sustainability concerns of bioenergy use, the sustainability criteria defined in the RED II, and the sustainability criteria implemented in voluntary schemes and national legislations, we only present the sustainability criteria that address the most urgent concerns (see Table 5.2). We have taken into account the monitoring of resource efficiency; however, a general definition of resource efficiency is still lacking and its effectiveness is location-, supply chain- and context-specific.[285] Nevertheless, we recommend that resource efficiency should at least be monitored. As iLUC criteria are not defined in the RED II, we consider the iLUC criteria following the definitions of the Delegated Regulation of iLUC risks.[292] Risk-based approach (RBA) was considered for forest biomass to assess evidence of compliance with SFM and carbon stock criteria when sustainability certification is not available. In theory, RBA could be used for agricultural biomass but since it has not yet been implemented for this biomass type, RBA was considered effective only for forest biomass. Socio-economic criteria were considered important, particularly for feedstocks mobilised in sourcing regions where local laws and rights are not implemented or not stringent enough to assure sustainability compliance.

Table 5.2. Sustainability criteria to assure bioenergy sustainability based on the most urgent concerns

Sustainability categories	Waste and residue[a]	Agricultural biomass	Forest biomass	Compared to Red II
Environmental criteria:				
- greenhouse gas emissions saving	√	√	√	Similar
- sustainable forest management			√	More stringent
- carbon stock preservation	√	√	√	More stringent
- biodiversity conservation		√	√	More stringent
- protection of air, soil and water	√	√	√	More comprehensive
- prevention of iLUC risks		√	√	Similar to definitions in the delegated ILUC regulation
Environmental category:				
- land use, land use change and forestry			√	*Similar*
Verification of sustainability compliance:				
- chain of custody	√	√	√	*Similar*
- risk based approach			√	*Additional*
Socio-economic criteria: binding to imported feedstocks				
- labour rights	√	√	√	*Additional*
- land rights		√	√	*Additional*
- food security		√	√	*Additional*
- resource efficiency	a monitoring of efficient biomass use			*Additional*

a *Including agricultural and forest residues*

5.4 NATIONAL LEGISLATIONS AND VOLUNTARY SCHEMES

5.4.1 Sustainability certification and reporting for liquid biofuels

Voluntary schemes recognised by the EC can be used to certify that biofuels are sustainably produced by verifying that they comply with the EU sustainability criteria. The recognised voluntary schemes have also been accepted by MSs in order to facilitate the functioning of the internal market and show sustainability evidence. However, the sustainability criteria defined in voluntary schemes are not similar as these schemes may include additional and more stringent criteria to demonstrate various pathways of sustainable biomass production and supply chains. The sustainability criteria established in the voluntary schemes recognised by the EC[293] and their additional criteria used to certify different sustainability scopes were compared with the effective sustainability criteria proposed in Table 5.2. We investigated how these sustainability criteria might be used to certify sustainable biofuels, but potentially also heat and electricity defined in the RED II. The assessed voluntary schemes include the International Sustainability and Carbon Certification (ISCC), Bonsucro, the Round Table on Responsible Soy (RTRS), RSB, the Biomass Biofuels voluntary scheme (2BSvs), the Red Tractor Farm Assurance Combinable Crops & Sugar Beet Scheme (Red Tractor), the Scottish Quality Farm Assured Combinable Crops (SQC), REDcert, Better Biomass, the Roundtable on Sustainable Palm Oil (RSPO), the Biograce tools, the HVO Verification Scheme (HVO), the Gafta Trade Assurance Scheme (GTAS), the KZR INIG System (KZR), the Trade Assurance Scheme for Combinable Crops (Trade Insurance), and the Universal Feed Assurance Scheme (UFAS).

Furthermore, there are also national legislations for biofuels. The national support schemes designed to implement national legislations and verify sustainability compliance were also reviewed. The UK Renewable Transport Fuel Obligation Order (RTFO) was selected for an assessment as their sustainability guidance for involved parties is transparent and informative.

5.4.2 Sustainability certification and reporting of solid biomass for heat and electricity

Several national legislations and industrial initiatives have established sustainability criteria and reporting requirements for heat production and electricity generation using solid biomass. The sustainability criteria are binding in related support schemes such as the UK Renewable Obligation Order for Solid Biomass (RO), the Dutch Stimulation of Sustainable Energy Production (SDE+), and the Belgian Green Certificates (GCs). The criteria may be also voluntary as in the voluntary initiative Danish Industry Agreement. These systems are designed to encourage the production of renewable energy from sustainable biomass, linked to specific national sustainability criteria and voluntary sustainability criteria. Economic operators can provide evidence that demonstrates a sustainability compliance with national authorities who verify the compliance proofs. As the systems in the Netherlands and the UK provide public and comprehensive guidance for bioenergy sustainability, they were assessed and compared with the RED II's sustainability criteria and verification requirements.

In addition, there are also widely-used voluntary schemes for solid biomass, including the Forest Stewardship Council (FSC), the Programme for the Endorsement of Forest Certification (PEFC) and the Sustainable Biomass Program (SBP). The FSC and PEFC establish various types of certification. The SBP, FSC and PEFC were assessed as they certify sustainable forest feedstocks. It should be noted that the FSC and PEFC assessed in this study include the FSC Controlled Wood and Chain of Custody as well as the PEFC Controlled Sources and Chain of Custody. Three schemes are recognised by Belgium, Denmark, the Netherlands and the UK, where sustainability criteria for solid biomass have already been implemented. These schemes can be used to demonstrate compliance with environmental, socio-economic criteria for forest biomass.

5.5 STAKEHOLDER CONSULTATION

The consultation was carried out from May 2018 to March 2019, with insight into the proposed RED II and adopted RED II. Invitations to the interviews were sent to twenty selected stakeholders, seven of whom agreed to be consulted. The online survey, with content similar to the questionnaire, received a total of fifteen responses and seven stakeholders completed the questionnaire; consequently, seven contributions were considered. The stakeholders included policy makers from Denmark, Italy and the Netherlands; scheme owners, and industry representatives, consultants and NGOs from Austria, Belgium, Germany, Ireland, the Netherlands and Switzerland. Although the number of responses did not allow a comprehensive coverage of all stakeholders, they provided valuable information on various sustainability aspects of bioenergy. The consultation results showed the points on which the stakeholders agreed most.

- *Validation of proposed sustainability criteria.* The effective sustainability criteria as proposed by this study were validated by all consulted stakeholders. They agreed that these sustainability criteria are important to assure sustainability compliance and are practical enough to be implemented. The consulted stakeholders provided additional information on various sustainability aspects:

<u>Environmental criteria:</u> Most of the stakeholders mentioned that it would still be complicated to apply iLUC measures in reality; therefore, the implementation of iLUC measurements still needs to be discussed among the MSs. The stakeholders agreed that inclusion of iLUC measures is necessary; but if iLUC is applied only to land used for biofuel production and not to other sectors using the same biomass, this may cause conflicts among these sectors and undermine the true meaning of sustainability compliance. The stakeholders also agreed that, in addition to the existing sustainability criteria, sustainable forest biomass use is important, and that a recognition of schemes safeguarding SFM is a positive step towards ensuring sustainability compliance. In the stakeholders' opinions, data collection of GHG calculation and other criteria for reporting and demonstrating sustainability is still unsatisfactory as they were deemed not completely verifiable.

<u>GHG emissions:</u> The stakeholders mostly agreed that a comprehensive and flexible tool allowing the inclusion of various aspects of the biomass value chains would be useful for GHG calculation. For conventional biofuels, a GHG-saving requirement of 70% would probably be difficult to achieve; however, for advanced fuels, this may well be possible. Although the GHG reduction threshold is certainly helpful, it is insufficient to stimulate the currently still immature market of advanced biofuels.

<u>Socio-economic aspects</u>: According to the stakeholders, an inclusion of socio-economic criteria is part of good governance. They highlighted that the compliance with laws,

land rights and worker rights is important and should be considered as a relevant sustainability criterion for certain feedstock use. Food security should not solely involve the biofuel industry but all the bioeconomy sectors.

Chain of custody: Stakeholders mentioned that while mass balance is a relevant chain of custody approach, there are still some sustainability risks. For example, different biomass fuels such as wood and straw pellets have been grouped together, and it is unclear what types of fuel are categorised as waste and residues, and what types of fuel are considered product. These uncertainties make it difficult to establish what sustainability criteria should be applied to demonstrate sustainability compliance.

- *Reporting guidance***.** The stakeholders consulted mentioned that in some MSs, guidance in sustainability reporting of biofuels, heat and electricity was relatively clear, but that more information was needed for economic operators on how to demonstrate compliance. For biofuels, the sustainability reporting was mainly proven by certificates issued from voluntary schemes, whilst for heat and electricity a combination was used of direct reporting to the authority and certificates in certain countries. According to the stakeholders, updates on the RED II adoption had been sufficiently provided to all related parties. However, for the establishment of sustainability criteria at the national level, more details are still required for feedstock classification, environmental impacts of feedstock use, and sustainability concerns of feedstock mobilisation (particularly imported feedstocks to the EU).

- *Usage and comprehensiveness of national legislations and voluntary schemes.* Besides accepting certificates provided by EU-recognised voluntary schemes, the UK, Italy, and Germany allow direct sustainability reporting to demonstrate the sustainability of biofuels. The stakeholders acknowledged that ISCC and REDcert schemes are frequently used in the EU, and they considered RSB to be the most comprehensive scheme, with stringent sustainability requirements for biofuels. The RSB is widely recognised because of the comprehensive coverage of feedstock types and the transparent reporting system.

- *Improvement of voluntary schemes.* The stakeholders stated that the voluntary scheme owners, auditors and verifiers were aware of legislative guidance and changes at EU level. The EU-recognised voluntary schemes are likely to be updated and improved upon following the adoption of RED II. They also stated that most voluntary schemes still need to be more transparent in documenting sustainability verification and certification. In addition, the stakeholders emphasised that coverage of additional supply chains for bioenergy is important and needs to be further considered by the voluntary schemes.

5.6 REVIEW OF SUSTAINABILITY CRITERIA IN NATIONAL LEGISLATIONS AND VOLUNTARY SCHEMES

5.6.1 Inclusion of sustainability criteria

The sustainability criteria defined in Table 5.2 were compared to national legislations and voluntary schemes. It was revealed that certain schemes already cover a variety of sustainability criteria for end uses and feedstock types. The Biograce I (for biofuels) and Biograce II (for solid and gaseous biomass) tools exclusively focus on GHG-saving criteria. It should be noted that from 2019 both Biograce tools are no longer recognised as voluntary schemes. The FSC and PEFC have been developed to safeguard SFM and wood supply regardless of the end uses of biomass. The SBP was developed to certify woody biomass supply to industrial, large-scale energy producers. Consequently, there is only a limited inclusion of sustainability requirements in the FSC, PEFC and SBP. There are six schemes which comprise comprehensive socio-economic criteria, namely the UK RTFO, UK RO, SDE+, Better Biomass, ISCC, and RSB. The RTFO & RO and SDE+ schemes are well established and provide regular updates on bioenergy development and sustainability compliance. Better Biomass, ISCC and RSB include various feedstock types and comprise sustainability criteria not only for bioenergy but also for sustainable biomaterials and biochemical production. Table 5.3 shows the inclusion of sustainability criteria under popular national schemes and voluntary schemes used in the EU.

Table 5.3. Inclusion of sustainability criteria in the national legislations and voluntary schemes for liquid biofuels and solid biomass. All" stands for all types of feedstocks, "F" stands for forest feedstock, "W" stands for waste and residues, "Ec" stands for energy crops. "x" represents sustainability criteria included in the scheme but does not present strictness level

		Schemes	Feedstock coverage	*Sectoral relevance*	*GHG emissions saving*	*Environmental criteria*						*Socio-economic criteria*			
						SFM	Carbon stock preservation	High biodiversity protection	Protection of water resources, air & soil	iLUC	LULUCF	Worker rights	Land right	Food price & security	Resource efficiency
Liquid biofuels	1	UK RTFO	*All*	*T*	x		x	x	x			x	x		
	2	ISCC	*All*	T, H, E	x	x	x	x	x			x	x	x	
	3	Bonsucro	*Ec*	T	x		x	x	x			x	x		
	4	RTRS	*Ec*	T	x		x	x	x			x	x		
	5	RSB	*All*	T, H, E	x	x	x	x	x	x	x	x	x	x	
	6	2BSvs	*Ec & W*	T	x		x	x	x			x			
	7	Red tractor	*Ec*	T			x	x							
	8	SQC	*Ec*	T			x	x							
	9	REDcert	*All*	T	x		x		x			x		x	
	10	Better Biomass	*All*	T	x		x	x	x	x		x	x	x	x
	11	RSPO	*Ec*	T	x		x	x							
	12	Biograce I, II	*All*	T, H, E	x										
	13	HVO	*Ec & W*	T	x		x	x							
	14	Gafta	*Ec*	T			x	x							
	15	KZR INIG System	*Ec & W*	T	x		x	x							
	16	TASCC	*Ec*	T	x		x	x							
	17	UFAS	*Ec*	T	x		x	x							
Solid biomass	18	UK RO	*F & W*	H&E	x	x	x	x							
	19	SDE+	*F, Ec & W*	H&E	x	x	x	x	x	x	x				
	20	FSC	*F*	T, H, E		x	x	x	x		x	x	x	x	
	21	PEFC	*F*	T, H, E		x		x	x		x	x	x	x	
	22	SBP	*F*	H&E	x	x		x	x		x	x	x	x	

5.6.2 Qualitative assessment of sustainability criteria and verification

The qualitative assessment only included sustainability criteria that are listed on the website of the national legislations and voluntary schemes. In the assessment the most relevant aspects of the effective sustainability criteria were summarised and discussed. Given the transition period from the implementation of RED I to the adoption of RED II, changes may have occurred after the assessment period. Any changes made after December 2018 have not been included in this study.

- Greenhouse gas emissions savings

In the RED II, two methods to calculate GHG emissions are defined: one method for transport fuels, biofuels and bioliquids and another method for biomass fuels used to generate electricity or to produce heat and cooling. Typical and default values (with no net GHG emissions from land use change are provided in the RED II for transport biofuels, electricity and heat from biomass. In view of the RED II's requirements for GHG emissions savings, two aspects were assessed to anticipate how the higher GHG emissions reduction for bioenergy can be met: (i) inclusion of additional feedstocks and (ii) inclusion of additional supply chains.

There are only six tools to calculate GHG emissions in the EU: the Biograce I and Biograce II, the ISCC tool, the RSB tool, the UK Biofuels Carbon Calculator and the Solid and Gaseous Biomass Carbon Calculator. The Biograce tools were widely used by voluntary schemes for calculating GHG emissions in accordance with RED I's guidance. The ISCC and RSB have developed separate tools to calculate GHG emissions in accordance with RED I's guidance, for the EU market as well as for the global market; both use Ecoinvent data for calculating GHG emissions of bioenergy and biomaterials.

The assessment revealed that the UK tools include comprehensive GHG emissions data and establish calculation methods similar to the RED II methodologies. The UK Biofuels Carbon Calculator provides a high number of default values for diverse feedstocks as well as various biofuel types. For example, it covers information of energy content and default GHG emission values (which are not available in the RED II) for biodiesel produced from animal waste or tallow. It also covers iLUC values for land-based crop biofuels. Moreover, the UK Biofuels Carbon Calculator also requires the economic operators to report emissions from fuel depots and filling stations beyond the duty points, to attain additional information on biofuel emission impacts. The UK Solid and Gaseous Biomass Carbon Calculator includes information for heat and electricity produced from diverse feedstocks, including feedstocks not defined in the RED II (such as bagasse pellets, olive cake pellets, and refuse-derived fuel). Both UK tools included a number of feedstocks that are used not only for the production of biogas, transport and advanced fuels but also for heat and electricity generation.

In principle, there are possibilities for updating calculation tools such that they take the RED II's methodologies into account. The RSB and ISCC methods are likely to be revised following the RED II updates. The UK tools are already compatible with the RED II's methodology in terms of both calculation method and system inclusion.

- Environmental aspects:

+ *High biodiversity protection:*

In the RED II, it is required that bioenergy produced from agricultural biomass is not made from raw material obtained from land with a high biodiversity value. All voluntary schemes recognised by the EC define sustainability criteria for high biodiversity protection. Some schemes require a higher level of biodiversity protection including maintenance, preservation and strengthening of high biodiversity value; these include the SDE+, Better Biomass, RSB, and REDcert. The FSC and PEFC include more detailed guidance and requirements. For example, the FSC requires full maintenance of retention trees (which stand permanently next to the regenerated trees to promote biodiversity), protection of endemic species as well as of rare, threatened and endangered species, and species of exceptional value. The PEFC clearly requires the prohibition of forest conversion.

The UK RO and REDcert indicate that they follow the biodiversity principles of both FSC and PEFC. The UK RTFO requires compliance with the RED I's biodiversity and carbon stock requirements, and further recommends using internationally recognised standards for demonstrating compliance with highly biodiverse and protected areas.

+ *Indirect land use change*

The Delegated Regulation of iLUC risks define feedstocks of high iLUC risks. Biofuels, bioliquids and biomass fuels may only be certified as low iLUC-risk fuels if they comply with GHG emissions-saving criteria and have been produced from additional feedstock obtained through additionality measures. Those measures cover (1) increasing productivity on the land already used, (2) cultivation of crops in areas that were previously not used for cultivation of crops (unused land), provided that a financial barrier has been overcome, or the land has been abandoned or severally degraded, or the crop has been cultivated by a small farmer; and (3) robust evidence proving that (1) and (2) have been met.

There are three schemes which include low iLUC risk criteria which are, to some degrees, similar to the criteria defined in the iLUC-delegated regulation. The SDE+ scheme requires low iLUC risks for biomass sourced from bioenergy plantation systems (equal or larger than 500 hectares) that were planted after 1 January 2008: the iLUC risks must be determined on the basis of the Low Indirect Impact Biofuels (LIIB) method [294] or an equivalent method. The ILLB method indicates that low iLUC risk biofuels can be achieved by increasing the crop yields and/or expanding agriculture on previously non-agricultural land with low carbon stocks and low biodiversity values. The RSB defines three indicators to be assessed for low iLUC feedstocks: (1) additional biomass is produced through a yield increase; (2) biomass is produced from land that was not previously cultivated or was not considered arable land; and (3) biomass is derived from existing supply chains and does not require dedicated cultivation of arable land. The RSB defines the low iLUC criteria as optional. Better Biomass gives biomass producers three different options to reduce iLUC risk: (1) growing biomass on previously unused land; (2) increasing productivity by actions such as shortening the period that arable land is left fallow, intensifying the use of grassland, and increasing the harvest frequency on arable land; and (3) integrating existing agriculture or forestry with additional biomass production.

Since April 2019, the ILUC Directive has been implemented in seven national legislations [11]. Five other MSs have stated that they anticipate the implementation of the ILUC Directive. However, it is unclear whether MSs have involved voluntary schemes in verifying iLUC and in what way voluntary schemes have certified low iLUC risks following national iLUC legislation.

+ *Preservation of high carbon stock - land use, land use change and forestry:*

The RED II defines criteria of high carbon stock to protect land with high carbon stock so that agricultural biomass used to produce energy cannot be made from. The RED II also defines LULUCF criteria to ensure that carbon stocks and sink levels in the forest are maintained or strengthened over the long term. To meet the LULUCF compliance, the country of origin of the forest biomass (1) must be a Party to the Paris Agreement; (2) must have submitted a nationally determined contribution to the UNFCCC; and (3) must have national or sub-national laws in place, in accordance with Article 5 of the Paris Agreement.

Carbon stock criteria similar to the RED II's definition have been established in most assessed schemes requiring that bioenergy is not made from raw material obtained from land with high-carbon, namely land that had one of the following statuses in January 2008 and no longer has the status of wetland, continuously forested area and land spanning.

The LULUCF criteria have been defined in five schemes in which the country level is not taken into account although the harvesting unit is considered the most important factor. The SDE+ scheme requires (1) that biomass production does not result in the destruction of carbon sinks or in long-term carbon debt; (2) that the forest management unit (FMU) is managed to retain or increase carbon stocks in the medium or long term; and (3) that biomass is not sourced from stumps unless for other reasons than wood or biomass production. The SBP requires that feedstock is not sourced from areas that have high carbon stocks and that analysis is provided to demonstrate that feedstock harvesting does not diminish the forest capability to act as an effective sink or to store carbon over the long term. Better Biomass requires the preservation of important carbon sinks in the vegetation and in the soil. The SDE+ and SBP schemes use 1 January 2008 as reference date whilst Better Biomass uses 1 January 2007.

The FSC demands that forests are protected because of their carbon stock function: management activities must maintain, enhance or restore carbon storage in the forest, including through forest protection and reduced impact logging practices for carbon. The PEFC requires (1) a consideration of positive impacts on long-term carbon sequestration capacity of forest vegetation, even with the conversion of severely degraded forests to forest plantations; (2) protective functions of forests for society, such as climate regulation and carbon sequestration; and (3) maintenance and enhancement of regulating or supporting ecosystem services.

+ *Sustainable forest management:*
The RED II includes criteria to minimise unsustainable production risks of forest biomass. It requires an application of national, sub-national or relevant laws which include legal sourcing, forest regeneration of harvested areas, protection of nature areas such as peatland and wetland, and maintenance of soil quality, biodiversity and long-term production capacity. The criteria for biodiversity protection and for soil, water and air protection, as parts of the SFM, were assessed separately as independent criteria. This section presented other SFM assurances: legal sourcing, maintenance of forest productivity, and ecosystem and nature conservation.

Several schemes were found to include comprehensive SFM criteria that go beyond the sustainability criteria of the RED II. The PEFC also requires that management, harvesting and regeneration operations must not reduce the production site capacity in the long term. The PEFC additionally requires anti-corruption measures and payment of applicable royalties and taxes. The FSC encourages the efficient use of the forest's multiple products and services to ensure a wide range of environmental, socio-conomic benefits. The FSC requires the protection of endangered plant and animal species as well as an enhancement of important ecological cycles. The SBP requires the maintenance of the health and vitality of ecosystems. The SDE+ scheme considers an FSC equivalent criteria for sustainable forest management. Better Biomass addresses long-term conservation of nature with associated ecosystem services and cultural values. The ISCC requires a producer to be able to prove good management practices and the establishment of continuous improvement. The RSB also requires ecosystem conservation.

+ *Protection of air, soil, and water:*
The protection of air, soil, and water is not yet considered a separate sustainability criterion in the RED II. In the EU, it can indirectly be assessed through the CAP, Forest Europe or national environmental regulations. However, a number of schemes certifying feedstocks from diverse sources already require this criterion as mandatory. Moreover, several schemes presented comprehensive sustainability requirements for the protection of air, soil, and water. Compliance with national laws and regulations relevant to the protection of air, soil, and water was found in the UK RTFO, the FSC, Better Biomass, the RSB and the ISCC. In general, evidence needs to be provided regarding the sustainable use of water resources, improvement of water and air quality, prevention of water pollution, sustainable management of soil and avoidance of erosion and air pollution.

The use of pesticides and other chemicals are under control and waste may not be discharged to water bodies and soil.

Some schemes such as the PEFC, the Bonsucro and the RSB also define their own criteria similar to the aforementioned criteria. The RTRS requires that pollution is minimised and generated waste is managed responsibly, that expansion of soil cultivation is responsibly managed, and that natural vegetation areas along watercourses are maintained or re-established. The RSB requires that operations implement practices that seek to reverse soil degradation and maintain soil health, and that they respect prior formal or customary water rights. The 2BSvs and REDcert clarify in their principles that sustainable biofuels should not be made from raw material produced on land where soil, water and air have not been protected. The SDE+ scheme requires that the soil quality of the FMU is maintained and if necessary improved, with special attention to coasts, riverbanks, erosion-sensitive areas and sloping landscapes.

+ *Socio-economic criteria:*

Socio-economic criteria are not defined in the RED II, but they are established in several national legislations and schemes. The most common criteria were assessed, including worker rights, land rights, food security and resource efficiency.

Regarding the *worker rights*, the UK RTFO and RO schemes require economic operators to prove that their biomass production does not in any way adversely affect the labour laws and worker rights, and that basic working conditions are met. Safety training is also obligatory. The ISCC, Bonsucro, RTRS, RSB, REDcert, Better Biomass, FSC, PEFC, and SBP schemes require compliance with national and local laws; or compliance with international standards and treaties related to working and employment, including child labour, forced labour, discrimination, freedom of association and the right of collective bargaining. In addition, the RTRS requires fair communication as well as opportunities for employments and provision of goods and services to be given to the local population. The FSC, PEFC, and SBP require the maintenance or improvement of the socio-economic well-being of workers. The ISCC, RTRS, Better Biomass, SBP, and FSC schemes require a verification of human health impacts. The RTRS states that integrated crop management techniques need to be implemented to reduce impact on human health. The FSC and PEFC also require providing opportunities for employment by making use of the socio-economic functions of forests and ecological benefits whilst still securing landscape and forest size.

Land rights are included in the UK's RTFO and RO, the ISCC, Bonsucro, the RSB, the SBP, the FSC, and the PEFC. Bonsucro, the RTRS, the RSB, the SBP, the FSC and the PEFC additionally state that any conflicts regarding land rights should be solved based on free prior informed consent. Water rights are included in the RTRS scheme. The FSC and the PEFC require that the legal and customary rights of indigenous peoples to own, use and manage their lands, territories, and resources are respected.

Food security is implemented as a criterion in the RSB, which includes a risk assessment to food security in the region as well as mitigation of any negative impacts that result from economic operations. The scheme supports local development and economic stability by holding the applicant accountable for improving the socio-economic conditions of local stakeholders affected by the operations in regions with poverty issues.

Cascading use of biomass is only required in Better Biomass; it is meant to ensure that feedstocks used for bioenergy production are raw material-efficient. A proof of compliance can be provided by a description of the material used as well as of the measures taken to foster the efficient use of raw materials.

Risk-based approach

A risk-based approach (RBA) is a method recommended in the RED II. An RBA is used to assess all forms of available evidence that indicates compliance with the SFM and carbon stock criteria when sustainability certification is not available at the sourcing area level. The RED II indicates that the RBA needs to be in accordance with the SFM principles developed under international forest processes such as Forest Europe [295] and SFM criteria are implemented through national laws or the best management practices. However, operational guidance on the verification of compliance with the RBA is not yet available under the RED II. The RBA is already implemented under the FSC, the PEFC, the SBP, the UK RO, and the SDE+ schemes.

The FSC includes an assessment of the risk of sourcing material from unacceptable sources, including risk related to the origin of feedstocks and to the mixing material in supply chains. Different methodologies can be used to assess, identify and designate risk, considering the likelihood and impact of non-conformity with FSC standards and indicators. Risk designations can be determined through a risk matrix, rating both the likelihood and the seriousness of negative impact. The PEFC also defines a management of risks. On-site inspection and reports from the actors in the supply chain and in the countries in which the products have been traded are taken into account.

The RBA defined in the UK RO is based on the regional risk assessment of the FSC, PEFC and other voluntary schemes. Credible and sufficient evidence must be provided to demonstrate the low risk of non-compliance for all wood fuel land, and then it can be considered legal and sustainable. At least 70% of the mix of consignments must be legal and sustainable for the consignments to be certified. Under the SDE+ scheme, the RBA is performed by the biomass producer (with an FMU smaller than 500 ha), and it may cover the supply bases of several biomass producers all together. The biomass producer gathers information on identified areas that is relevant for a risk analysis with respect to the SFM requirements. The risk of non-compliance is assessed for each SFM criterion, using adequate risk analysis methods, and subsequently implementing mitigating measures if necessary. The SBP scheme requires the certified biomass producer to implement the RBA defined in the SDE+ scheme.

Chain of custody

Both the RED I and RED II include a verification approach - mass balance which is a chain of custody (CoC). More detailed guidance is provided under the RED II. Mass balance allows mixing of consignments of raw material or fuels with differing sustainability characteristics and GHG emissions savings or different energy content, but it is necessary that sustainability compliance can still be verified. The size of the consignments and the related quantities of sustainability and GHG emissions-saving characteristics are adjusted by applying a conversion factor; the mass balance is then applied accordingly.

Mass balance is established in all assessed national legislations and voluntary schemes. Under the UK RTFO and RO, two COCs, mass balance and physical segregation are operated at the company level or at a more detailed level of granularity. The time frame is also strict under the UK schemes: parties in the supply chain need to undertake a periodic inventory of site-level carbon and sustainability data at least on a monthly basis. Parties using an EC recognised voluntary scheme will follow the time frame of that voluntary scheme. The SDE+ requires that the same mass balance is applied to the group as to individual businesses. A mass balance calculation is required for each geographical site, and it may relate to a period of no more than 12 months. If a positive balance (credit for sustainability compliance) remains, that surplus may be transferred to the following period of 12 months.

The ISCC, Better Biomass, RSB, GTAS, Bonsucro, and RTRS define the comprehensive guidance for the use of a mass balance system as follows: when batches with different or no sustainability are physically mixed, the sizes and sustainability characteristics of each batch remain assigned to the batches in the calculation for either mass balance or segregation; documentation on traceability and mass balance must be updated and fully accessible to the auditors. With Bonsucro, the economic operator must define the unit of certification. The RTRS additionally requires data to be valid for 24 months from the first date recorded in the system. The RSB clarifies that whenever the participating operator combines batches of certified material with different GHG emission values, they will either use the GHG emissions savings of the batch with the lowest GHG emissions savings, or track the GHG values individually. The REDcert requires mass balancing for the sum of all consignments withdrawn from the mixture to be described as having the same sustainability characteristics, in the same quantities, as the sum of all consignments added to the mixture.

The FSC requires the organisation to implement and maintain a CoC management system appropriate to its size and complexity to ensure its continuous conformity to all applicable certification requirements, and it also requires that all records are retained for a minimum period of 5 years. Regarding control of FSC claims, guidance is provided for single, multi-site and group CoC certification. The PEFC establishes two optional CoC approaches: (1) the physical separation method may apply to the certified products with various content of certified material, and (2) the percentage-based method considers material entering and leaving the group of products have the same measurement units. There is no fixed time frame for the verification of the material; instead, the PEFC requires on-site inspection to be carried out whenever relevant. The SBP defines a supply base in which feedstocks can be traced back and the feedstock input profile is described and categorised by the mix of inputs.

5.7 DISCUSSION AND CONCLUSIONS

5.7.1 Discussion

This study has assessed sustainability criteria defined for bioenergy in the RED II, national legislations and voluntary schemes. Based on the stakeholder consultation and the assessment of effective sustainability criteria, there are several aspects which need to be considered further by policy makers, voluntary scheme owners and other involved parties.

a. Sustainability criteria

- *Compliance with laws and regulations*. Most of the national legislations and voluntary schemes include legal compliance in sourcing countries. Local laws may not be established, may not be stringent enough or may not be enforced, and as a result, sustainability compliance is not adequately safeguarded. For compliance with the sustainability criteria for high biodiversity values, peatland and forest biomass, it is stated in the RED II that the EC may recognise a list of protection areas defined by the International Union for the Conservation of Nature (IUCN) or defined by international agreements. The RED II provides no guidance in responding to socio-economic concerns. In case the related laws are not in effect, we recommend two lists of known international standards in Annexes 3 and 4 for the preservation of biodiversity, ecosystem values and conservation values as well as for social aspects. These standards are widely applied at global level to respond to sustainability concerns.[296,297] Policy makers and scheme owners may consider adopting those standards as proof of sustainability compliance.

- *Remaining concerns about iLUC, waste and residues.* The iLUC criteria are deemed important to respond to public concerns regarding the unsustainable production of biomass; since iLUC measurements have already been implemented at MS level, they were included in this study as a possible effective sustainability criterion. However, it still needs to be seen to what extent iLUC measurements help to assure sustainable land use, as little information has been given so far. The iLUC criteria have only to a limited extent been adopted in voluntary schemes, and it remains largely unclear how the iLUC criteria have been implemented in these voluntary schemes. We propose that policy makers, voluntary scheme owners and sustainability practitioners agree on measures for increasing the effectiveness of iLUC criteria, and on how to overcome challenges. It should also be noted that at EU level, the adoption of the RED II and the Delegated ILUC Regulation has initiated a World Trade Organisation (WTO) dispute between the EU and some sourcing countries.[298,299] The EU has stated that the RED II and the Delegated ILUC Regulation were established to respond to environmental concerns, while the WTO states that governments themselves have the right to deal with environmental impacts.[300] However, the WTO has not yet issued a final verdict in this dispute.

Regarding waste and residues, the RED II specifies that these feedstocks need to fulfil only the GHG emissions-saving requirements. Waste and residues from agricultural land are exempted from soil quality and soil carbon criteria if monitoring or management plans that address the impacts are in place. Oil palm, soybean and sugar cane are produced in some regions that are considered to have high iLUC risks,[301] thus it remains unclear how residues from these crops can meet the iLUC criteria. Using waste and residues from those feedstocks are deemed sustainable following the RED II guidance, but NGOs might disagree. Therefore, we anticipate that clarification and agreement need to be achieved by policy makers and involved parties on whether waste and residues from high iLUC risk feedstocks are eligible, and on what sustainability criteria might be relevant. Additional guidance on measuring iLUC risks and provision of consistent category of waste and residues would be helpful for actors involved in the verification and certification of sustainable feedstocks.

- *Risk-based approach:* The RBA is already implemented in several national legislations and voluntary schemes. However, the risk assessment differs among these systems. Whilst the scope for an RBA is stated in the SDE+, risk assessment is decided and based on sustainability concerns of controlled wood categories in the FSC, controlled sources and materials in PEFC. Therefore, selection of a relevant RBA still needs to be decided by policy makers.

- *Installation capacity.* The RED II defines the total rated thermal inputs for plants producing bioenergy. This requirement is in line with the capacity defined in the EU Emission Trading System and may help to minimise administrative costs for operators.[302] In reality, several MSs already require compliance for plants with a smaller capacity. In the UK, a generating station using biomass of 50 kW capacity have to report against sustainability criteria,[279] and in the Netherlands, a 5 MW wood pellet steam boiler [303] also needs to demonstrate its sustainability compliance. As also indicated in the RED

II, defining a threshold is permitted at MS level. Thus, we suggest that policy makers carefully consider a suitable plant capacity in their country to avoid leakage: feedstocks which do meet sustainability criteria to feed in plants of high capacity in one country might be sold to produce bioenergy in plants of low capacity in other countries.

- *Sustainability criteria*. Binding sustainability criteria defined in the RED II are fixed for biofuels and bioliquids, but additional sustainability criteria may be established for solid biomass in the MSs. The effective sustainability criteria proposed in this study and approved by consulted stakeholders are more comprehensive than in the RED II. However, too many requirements to demonstrate sustainability compliance may cause effective sustainability criteria to become ineffective. To facilitate the sustainability compliance of feedstocks mobilised in sourcing countries, policy makers and voluntary scheme owners may consider accepting stringent national legislations or stringent sustainability criteria on the protection of air, soil and water, or socio-economic compliance in certain voluntary schemes. These might be practical solutions to avoid the administrative costs of certification, and it may be less time consuming for economic operators. However, national laws and voluntary schemes that include relevant criteria compatible with effective sustainability criteria need to be discussed and assessed, ideally at EU level. The assessment helps facilitate sustainability compliance with sustainable sourcing of biomass.

b. Verification and certification

Overall, national legislations and voluntary schemes which establish comprehensive sustainability criteria for bioenergy in their systems are deemed efficient to safeguard sustainable bioenergy. Various environmental, socio-economic sustainability criteria have already been implemented in certain national legislations and voluntary schemes.[132,279,303,304] For MSs which aim to establish stringent sustainability criteria in their national legislations for agricultural biomass, waste and residues, we recommend considering the sustainability criteria in the RSB, and to a lesser extent in the UK RTFO, Better Biomass and REDcert schemes. For stringent sustainability criteria used for forest biomass, we recommend the FSC and the UK RO schemes. Regarding GHG emission savings, calculations can be based on the RED II guidance, and the UK RTFO and RO schemes.

For MSs which aim to follow closely the sustainability criteria defined in the RED II, we recommend considering our summary of sustainability criteria in Table 3 and to review our qualitative assessment of various schemes in subsection 6.2. However, it is also important to note that the development of certification systems for biomass sustainability is a continuous process, changes may have happened or may still occur in these schemes.

c. Study limitations

Since the adoption of the RED II, progress has been made in transposing sustainability criteria into national legislations, and similar progress has been made in certain voluntary schemes. Nevertheless, consultation with the stakeholders in Eastern Europe, where some countries play important roles as sourcing countries of biomass, proved not to be possible. As a result, efforts to assure sustainability compliance and to certify sustainable bioenergy could not be fully investigated. It is recommended that in future research there is more communication with stakeholders in biomass-sourcing countries. The communication may better address challenges of implementing sustainability compliance, and efficient monitoring of sustainability compliance.

5.7.2 Conclusions and Recommendations

Challenges of the RED II's implementation. The RED II defines binding sustainability criteria for the whole bioenergy sector; thus, it plays an important role in safeguarding sustainable biomass and bioenergy supply in the EU in the near future. However, the RED II also presents new challenges to the transposition of sustainability criteria at MS level. These challenges include a scope extension to new end-use sectors, including heat and electricity; a scope expansion to advanced biofuels; and additional and updated sustainability criteria to agriculture and forest biomass. This study also shows that the RED II's sustainability criteria are deficient in avoiding some risks of unsustainable forest management, lack stringent protection of air, soil and water resources, and lack socio-economic criteria which are relevant for biomass feedstocks imported to the EU. The transposition and implementation of the RED II will be difficult without detailed guidance on certain sustainability criteria and their indicators.

Effective sustainability criteria. In this study, we propose effective sustainability criteria to tackle the sustainability concerns to assure bioenergy sustainability which are not addressed in the RED II. The effective sustainability criteria for waste and residues involve GHG emission savings; carbon stock preservation; protection of water, soil and air; and labour rights. Besides these, the effective sustainability criteria for agricultural biomass also include biodiversity conservation, prevention of high iLUC risks, land rights and food security. The effective sustainability criteria and requirements are most stringent and comprehensive for forest biomass, and they further include the SFM, a LULUCF-reporting and risk-based approach. Reporting the cascading use of biomass has been considered, but we decided that it unnecessarily acts as an effective sustainability requirement since there has been no agreement yet on a consistent definition. We recommend that policy makers and voluntary scheme owners to consider our findings in transposing sustainability criteria into national legislations and voluntary schemes.

Our study also finds that it is possible to establish effective sustainability criteria for various bioenergy types. However, the systems most recognised by policy makers and involved parties still need to be agreed upon and legitimised. Recognition of voluntary schemes by national authorities may increase the legitimacy of certification, trigger further efficiency of sustainability compliance, and stimulate further implementation of effective sustainability.

Perspective of sustainable bioenergy and bioeconomy. To establish legislation for bioenergy sustainability, mutual discussion among policy makers on various definitions and measurements of sustainability criteria are very important. The discussion should aim to avoid emission leakage, impacts to biodiversity and ecosystems, socio-economic conflicts and trade barriers among the MSs. With new sustainability criteria for the whole bioenergy sector defined in RED II, existing voluntary schemes may consider expanding their certification scope, revising the existing sustainability criteria, and/or recognising other voluntary schemes to facilitate sustainability compliance. To a higher level of assuring bioenergy sustainability than the RED II indication, policy makers in the MSs are also advised to work with voluntary scheme officers and the scientific community. This will help to clarify pending sustainability concerns, and will promote the establishment and implementation of sustainability criteria in a transparent and consistent way.

Bioenergy is part of the wider bioeconomy which involves various sectors such as biomaterials and biochemicals. Binding sustainability criteria established for the bioenergy sector but not for other sectors using the same feedstocks may provoke leakages and trade-offs between sectors as well as debates on a meaningful sustainability performance. One example is that certified feedstocks may be used for bioenergy production whilst uncertified feedstocks are used for the production of biomaterials, biochemicals and feed. The sustainability aspects that must be considered in order to assure sustainability compliance among these sectors need to be agreed upon by the stakeholders involved. An example may be the question how multifunctionality must be dealt with for biorefineries using biomass feedstocks and producing multiple outputs including bioenergy. More collaborations between stakeholders from different sectors are indispensable for exchanging information and sharing the lessons learnt in demonstrating sustainability performance.

There is little time left before the RED II will come into force on 1 January 2021, and therefore communication between the involved stakeholders needs to be carried out efficiently and promptly.

SUPPLEMENTARY INFORMATION

S.I.5.1 Terminology and definitions

Bioenergy includes three different types: biofuels, bioliquids and biomass fuels. These bioenergy types are briefly defined in the RED I and RED II. For clarifications, they are further explained as below.

Biofuels: Biofuels are liquid or gaseous transport fuels such as biodiesel and bioethanol which are made from biomass. They serve as a renewable alternative to fossil fuels in the transport sector. In the EU, biofuels are used to help reduce greenhouse gas emissions and improve the EU's security of supply. By 2020, the EU aims to have 10% of the transport fuel of every EU country come from renewable sources such as biofuels.[305]

Bioliquids: Bioliquids are liquid fuels made from biomass used for energy purposes other than transport, e.g. in heat and electricity sector.[272,306]

Biomass fuels: Biomass fuels means gaseous and solid fuels produced from biomass [307]. They are available in a number of different formats, varying from a fine dust and sawdust to chips, pellets, briquettes, and bales and as liquids. Biomass fuels are renewable, sustainable, and environmentally friendly if they are produced and used in a sensible and responsible way, but can also cause irreversible damage to the environment if produced or used in other ways. They can benefit local communities and in some cases can even be beneficial to biodiversity. They can be used to compensate for one of the major weaknesses of wind power, its intermittent and unpredictable availability, as biomass can be stored and dispatched when needed. There are many technical and logistical challenges to fit biomass into the current power infrastructure, but this is likely to change when the generation mix changes as older fossil-fueled power stations are decommissioned.[308]

Solid biomass such as wood can directly be burnt to produce heat and electricity. Solid biomass is a type of biomass fuels and is a terminology which is popularly mentioned by MSs where legislations and sustainability initiatives for sustainable heat production and electricity generation are established.

Voluntary scheme: are referred to certification schemes which verify and certify that bioenergy is sustainably produced by the compliance with defined sustainability criteria set in a system. They can also be referred to tools used to demonstrate compliance with Renewable Energy Directive's sustainability criteria.

S.I.5.2 List of assessed national schemes and voluntary schemes

For liquid biofuels:

› Biomass Biofuels voluntary scheme 2BSVS: https://www.2bsvs.org/
› Better Biomass: http://www.betterbiomass.com/
› Biograce: https://www.biograce.net/
Bonsucro: http://www.bonsucro.com/
› Gafta Trade Assurance Scheme : https://www.gafta.com/
› Forest Stewardship Council : https://www.fsc.org/
› International Sustainability and Carbon Certification: https://www.iscc-system.org/
› KZR INIG System: http://www.kzr.inig.eu/
› Programme for Endorsement of Forest Certification Schemes: https://www.pefc.org/
› REDcert: https://www.redcert.org/en/
› Round Table on Responsible Soy: http://www.responsiblesoy.org/?lang=en
› Roundtable on Sustainable Palm Oil: https://www.rspo.org/
› Roundtable for Sustainable Biomaterials: https://rsb.org/
Scottish Quality Farm Assured Combinable Crops scheme: http://www.sqcrops.co.uk/
› Trade Assurance Scheme for Combinable Crops: https://www.agindustries.org.uk/home/
› Universal Feed Assurance Scheme: https://www.agindustries.org.uk/home/
› UK Renewable Transport Fuel Obligation : https://www.gov.uk/transport/renewable-fuels

For solid biomass

› Netherlands Stimulering Duurzame Energieproductie: https://www.rvo.nl/subsidies-regelingen/stimulering-duurzame-energieproductie/categorie%C3%ABn/biomassa-sde
› UK Renewable Obligation: https://www.ofgem.gov.uk/environmental-programmes/ro

S.I.5.3 Recommended internationally recognised list for the preservation of biodiversity, ecosystems and conservation values

1. The World Conservation Union "IUCN" Category I - IV protected area categories
2. World Database on Protected Areas: http://www.protectedplanet.net/
3. Wetlands of international importance designated under the Ramsar Convention: http://ramsar.wetlands.org/
4. World Heritage Sites designated under the UNESCO World Heritage Convention: http://whc.unesco.org/en/list
5. Biosphere Reserves designated under the UNESCO Man and the Biosphere Programme http://www.unesco.org/new/en/natural-sciences/environment/ecological-sciences/biosphere-reserves/
6. UNESCO World Heritage Site: https://whc.unesco.org/en/list/
7. The RaMSar Convention on Wetlands of International Importance: https://www.ramsar.org/sites-countries/ramsar-sites-around-the-world

S.I.5.4 Recommended social standards

1. Labour standards: https://www.ilo.org/global/standards/lang--en/index.htm
2. Sustainable Development Goals adopted all United Nation MSs: https://sustainabledevelopment.un.org/?menu=1300

S.I.5.4 Questionnaire content used for the online survey and the interviews with invited stakeholders: Sustainability criteria and reporting requirements for biofuels & bioenergy

As part of the project AdvanceFuel (http://advancefuel.eu/), there is a study focusing on the development and implementation of common standards and certification schemes for sustainable biofuels production. Consultation with various stakeholders is therefore important to complete the study.

Policy Field	Renewable Energy and Transport Biofuels
Target Groups	Biofuel industry, certification scheme owners, & auditors
Period of Consultations	01/03/2018 – 30/03/2019

Given the changing legislation for biofuels at a EU level including higher share for advanced biofuels produced from various lignocellulosic biomass feedstocks, the objective of this study are:

- to investigate inclusive ***sustainability requirements for biofuels*** (including advanced biofuels, aviation biofuels and other liquid renewable fuels) in the European member states
- to receive update ***on the existing legislation*** governing the sustainable production and use of feedstocks for biofuel types and to check whether current national initiatives are undergoing changes/updates, e.g. to include additional sustainability criteria defined for heat and power for demonstrating biofuel sustainability compliance
- to confirm the ***list of certification schemes*** used to demonstrate sustainability compliance with national initiatives; to verify if there are any ***further updates or improvements in the certification schemes*** used to demonstrate compliance with current and future legislation
- to apprehend the response, viewpoints and expectation of various stakeholders towards the ***comprehensive national and European sustainability requirements*** for bioenergy

Expected Outcome:

- an overview of the existing and planned legislation for all (current and new) biofuel types in the member states, showing common elements and differences, highlighting possible barriers to trade and cumbersome administration
- a workshop on the possibilities for (future) alignment/ and or harmonisation of sustainability requirements and sustainability certification schemes with the participation of policy makers and various industry
- a report and scientific paper on the same topic

General information:

Your country	**Please choose**
Your position	**Please choose**
Your contact information	(email & telephone number if applicable)
National scheme	Name and website of (national) scheme/ initiatives for bioenergy
National updates	Please clarify if there are any updates on sustainability requirements for bioenergy/ and or biofuels

Sustainability Reporting:

Direct reporting: Do biofuel suppliers report directly to the national authority regarding sustainability compliance? Is the guidance and administrative procedure clear and effective?

Reporting by sustainability certificates provided by certification schemes:

- Certificate proofs: Do biofuel suppliers also participate in certification schemes? Could you describe those? What are the most popular/ accepted certification scheme(s)? Why are they chosen? In how far does the price vary between different certification schemes?
- Certification schemes: In addition to certification schemes accepted by the EC used for biofuels and bioenergy, are there other national and/ or applicable schemes that you are aware of? Could you name those?

+ Are, in your opinion, certification schemes useful or even necessary for demonstrating compliance, or would e.g. the presence of existing legislation in your opinion be sufficient?

+ What are, in your opinion, the certification systems with most comprehensive sustainability criteria to demonstrate sustainability compliance?

+ How ambitious those schemes are regarding their certification of bioenergy at EU and international level?

Cross-border business: Biofuel suppliers may have a number of international branches or factories. They can use voluntary schemes recognised by the EC to prove sustainability compliance in order to receive subsidies/ grants. Are you aware of a national regulator issuing sustainability certificates such as the UK Renewable Transport Fuel Obligation also recognised in other countries?

If no, do UK biofuel suppliers need to use certificates issued by voluntary schemes if they have cross-border business?

Scheme improvement: In your opinions, how do sustainability certification schemes need to be improved to facilitate (current and new) biofuel compliance and trade?

Sustainability criteria:

Feedstock production and land use:

+ Certified biofuels: In your country, what is the volume of certified transport biofuels to meet national renewable target? Is currently certified biofuel volume produced domestically or mainly imported?

+ Deployment and role of advanced biofuels: In your country, are there strategies for advanced fuels deployment and/ or is commercial deployment of process technology for advanced biofuels taking place? How do you view the future regarding the contributions of sustainable advanced biofuels to the national renewable energy target?

+ Indirect land use change (iLUC): iLUC has been raised to cause some environmental issues (e.g. expansion of agricultural and forest land for bioenergy crops causing food insecurity, deforestation and other GHG emitting land use changes etc.). In your view, should iLUC be included as a sustainability criterion? Do you think the definition and methods to quantify iLUC are clear and effective?

+ Environmental aspects: In your opinion, what are the necessary environmental sustainability criteria to be included for sustainability compliance:

Sustainable forest management:

- ◻ Legal & sustainable sourcing
- ◻ Forest productivity & functioning

- ◻ Carbon stock
- ◻ Biodiversity protection
- ◻ Ecosystem conservation
- ◻ Protection of water resources, air, soil
- ◻ iLUC
- ◻ (others, please indicate your recommendations)

- Data collection: In your opinion, data collection requirements for the GHG calculation and other sustainability criteria demonstration are relevant and verifiable? Do you consider guidance for biofuels are clear and comprehensive? What could still be improved for future use?

- GHG emissions:

  GHG emission threshold: RED recast requires at least 50% savings of greenhouse gas (GHG) emissions from biofuels compared to fossil fuels in 2017 and requires higher threshold of at least 70% for installations starting operation in 2021.

  Do you consider the GHG emissions reduction achievable for all domestic biofuel consumption in your country? In your view, are there enough feedstocks available to meet a stricter GHG emissions reduction in the future?

- Calculation tool:

  What tools are used to calculate biofuel GHG emissions? Visioning the same feedstocks which could be used for biofuels, heat and electricity, do you think separate tools used to calculate GHG emissions for biofuels and heat/power production necessary?

  In case the same sustainability criteria are required for heat, electricity and biofuel sectors, in your opinions whether the tools should or should not be incorporated?

- Chain of custody

Mass balance is the only chain of custody (CoC) system currently accepted under the Renewable Energy Directive. Do you think it is sufficient to administratively separate certified biomass from non-certified products in the supply chain following the mass balance approach? Do you think the mass balance approach is strict enough?

- Socio-economic aspects

Social sustainability requirements are not yet required for biofuel sustainability compliance at EU and national level.

In your opinion, what are the most important social aspects to be considerably included for sustainability compliance:

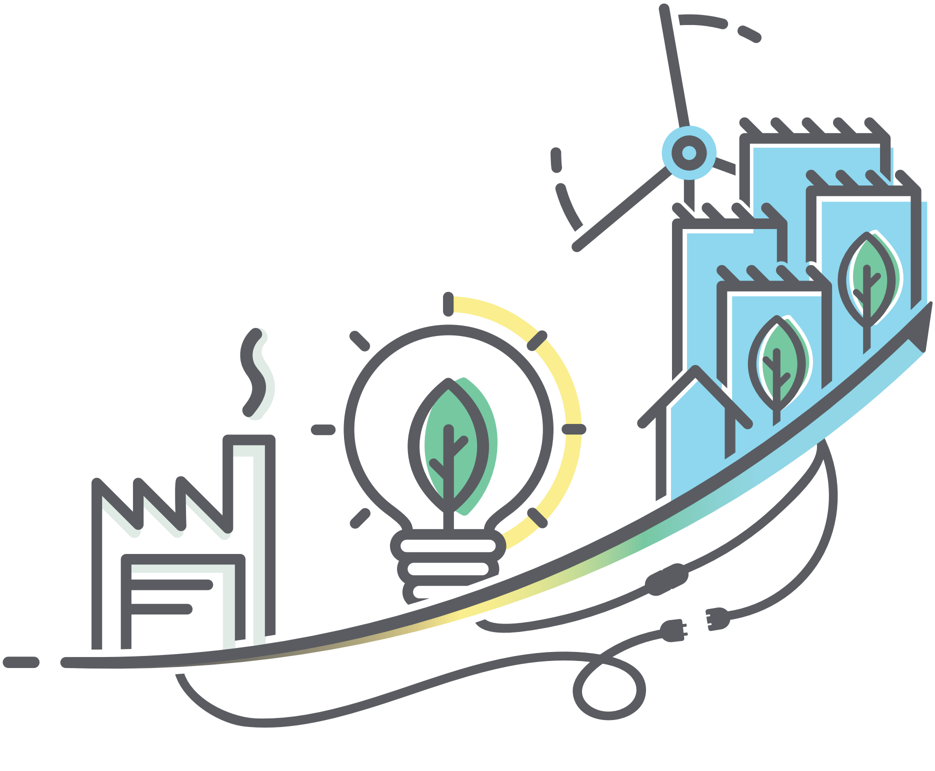
- ◻ Compliance with laws and local right
- ◻ Child labour
- ◻ Land right
- ◻ Human health impacts
- ◻ (others, please provide your recommendations)

In your opinion, what are the most important economic aspects to be included for sustainability compliance:

- ◻ Food security
- ◻ Rural development/ economic stability
- ◻ (others, please provide your recommendations)

Harmonised sustainability requirements

- › In your opinion, are the current sustainability criteria for biofuels set in the Renewable Energy Directive (RED) recast are complete/ fair/ too rigid? Please explain your point of view.
- › Several sustainability criteria have been set to govern the sustainable production of biofuels. In the future, diverse biomass types are also used for the production of advanced biofuels, and also for heat and electricity. In your opinion, whether or not sustainability criteria for biofuels, heat and electricity generation are identical at EU level? And according to you, should sustainability criteria also be required for other industries including the chemicals, materials, paper, construction and food?



6

Conclusions and Recommendations

Bioenergy has important roles to tackle climate change and lower dependence on fossil fuel use. In addition to other renewables such as solar, wind, and hydropower, bioenergy is needed for transformation of the global energy sector from fossil fuels dominated to renewable and carbon-neutral by the 2050. Bioenergy has been promoted by both national and international policies to increase the share of renewable energy supply. In addition to the increase of modern bioenergy consumption, a large difference between regions with a surplus of biomass and regions with high (renewable) energy demand and limited biomass resources has fostered international biomass trade of solid biomass and liquid biofuels.

Although the role of bioenergy in the energy transition is recognised, the growth of modern bioenergy and international bioenergy trade has led to environmental concerns of stakeholders. These include low reduction of GHG emissions; unsustainable forest management; negative impacts on biodiversity, soil, and water. Also social and economic concerns particularly in sourcing countries are addressed by some stakeholder groups. Production and mobilisation of sustainable biomass, particularly in international sourcing countries has not yet been comprehensively investigated. Therefore, certain stakeholder groups consider that only limited sustainable biomass would be available for bioenergy production.[309,310] To respond to these concerns, linked to policy support for bioenergy, efforts have been made towards sustainable governance of bioenergy through legislation, implementation of voluntary sustainability criteria and certification, and best practices. For example, the Renewable Energy Directive (RED I) established EU wide legally binding sustainability criteria to biofuels and other liquid fuels in 2009. Some national legislations and industrial initiatives in the EU have also implemented a set of sustainability criteria for solid biomass. Since 2018, more comprehensive and additional binding sustainability criteria have been defined in the Renewable Energy Directive Recast (RED II) for the whole bioenergy sectors. However, the aforementioned sustainability concerns have not yet been fully addressed.

Currently, the global export regions of wood pellets for bioenergy include the US, Canada, and Russia.[311] Other regions such as Estonia and Vietnam are also expected to be large export regions. In addition to wood pellets and biofuels, other biomass types such as wood chips, industrial round-woods, and particles of which by-products can be used indirectly for energy purposes, are expected to be highly traded internationally. Investigation of biomass export potentials with low costs is considered important for import regions to reduce their national dependence on fossil fuels import. In addition to competitive export potentials, investigation of sustainable lignocellulosic biomass potentials is important for the EU and other import regions to reduce GHG emissions in the energy sectors and assure sustainability of bioenergy.

The main objective of this thesis is thus to investigate the required conditions for the bioenergy sector to move towards more sustainable pathways. The thesis focuses on lignocellulosic feedstocks that are considered promising for the production of bio-based products as well as biofuels, heat, and electricity. The following research questions are addressed:

I. What are different concerns raised by stakeholders regarding environmental, socio-economic impacts of bioenergy? What are their position and vision towards sustainable bioenergy?
II. What are the main factors determining sustainable biomass potentials in various sourcing regions? What are the resulting sustainable export potentials?
III. What are effective sustainability criteria for bioenergy, taking into account wider sustainability concerns and practial implementation issues?

6

Table 6.1 provides an overview of chapters and which RQ(s) they address. It is followed by a summary of the main chapters of the thesis, the answers of the research questions, a reflection on policy cycles, and recommendations linked with key elements of developing sustainability frameworks for bioeconomy pathways.

Table 6.1. Overview of the chapters and the addressed research questions

	Chapters	**Research questions**		
		I	II	III
2	Towards a harmonisation of national sustainability requirements and criteria for solid biomass			x
3	Charting global position and vision of stakeholders towards sustainable bioenergy	x		x
4	Sourcing overseas biomass for EU ambitions: assessing net sustainable export potential from various sourcing countries		x	
5	Effective sustainability criteria and certification for bioenergy sector at EU level: Towards the implementation of the Renewable Energy Directive II	x		x

6.1 CHAPTER SUMMARY

Chapter 2 compared sustainability criteria and reporting requirements in national sustainability support schemes and voluntary initiative of the four countries that import solid biomass for heat and electricity generation, Belgium, Denmark, the Netherlands, and the UK. In the absence of EU-wide sustainability criteria for solid biomass, different sustainability criteria established at national level might impose barriers to demonstrate sustainability compliance. Different requirements might be a barrier to trade. The comparison identified some possibilities for harmonisation to mitigate these barriers and provided suggestions for policymakers for the improvement and alignment of national sustainability requirements.

Regarding the scope of feedstock use, agricultural and forest biomass feedstocks were included in all national support schemes, except in Denmark where only forest biomass was included. Regarding the end-use, three countries used solid biomass for electricity and heat generation, namely Denmark (combined heat and electricity), the Netherlands (co-firing in existing coal power plants and large-scale heat producers) and the UK (heat, power plants, and co-firing in existing coal power plants). In Belgium the scope was limited to electricity generation. Belgium, the Netherlands, and the UK applied legally binding sustainability requirements for solid biomass linked to the national support schemes. In Denmark, compliance with sustainability requirements was regulated through a voluntary industry agreement. The sustainability criteria and reporting requirements were most comprehensive in the UK, the Netherlands, and Denmark while it was rather limited in Belgium. The criteria of GHG emission savings and SFM were included in the four countries, whilst compliance with local laws regarding social and work rights were covered in Denmark, the Netherlands, and the UK. ILUC and carbon debt criteria were only implemented in the Netherlands.

The results showed that there were only a few sustainability requirements that were compatible and could be fully harmonised between the assessed countries. Hamonisation could be possible for certain sustainability criteria defined for woody biomass including legal sourcing, biodiversity protection, and maintenance of forest productivity. The Dutch legislation implemented several sustainability requirements that were not included in the other countries, and it was therefore likely to hinder Dutch biomass suppliers and generators from importing biomass.

To demonstrate sustainability compliance, biomass suppliers and generators might use more than one voluntary scheme, or a combination of voluntary schemes including voluntary schemes that are approved by the EC. Usage of these recognised schemes as such may help to reduce cost burden and complexity in providing evidence of sustainability compliance of solid biomass where sustainability criteria were required. The usage may ultimately facilitate biomass trade from various sourcing regions. Some voluntary certification schemes were recognised in the national systems including SBP, FSC, and PEFC. SBP was aligned with most of the UK sustainability criteria, whilst FSC 100% compliant and PEFC 100% compliant were fully recognised in the Netherlands.

A consultation with various stakeholders on the implementation of sustainability criteria was also carried out. In general, the consulted stakeholders acknowledged the importance of establishment and implementation of sustainability requirements for solid biomass on the short term at a national level as no binding sustainability criteria were required at EU level. However significant time and resources were needed to collect data and demonstrate sustainability compliance with GHG emission savings and land criteria.

Ultimately, a decision at the EU level regarding the use of GHG emission calculation tools, data collection and default values for biomass types would be preferred by biomass suppliers and producers, as it would likely bring greater consistency and harmonisation. Ideally, a single authority such as the EC Joint Research Centre could provide information related to GHG emissions. This would already lead to a basic level of harmonisation. In addition, an establishment of a harmonised voluntary certification scheme was suggested in the short term based on legislative requirements in the four countries and in voluntary initiatives. Such a harmonised certification scheme may also reduce both implementation costs and complexity for biomass suppliers and generators. In the long term, binding criteria on sustainability requirements for solid biomass was recommended at EU level.

Chapter 3 broadly examined the position and vision of a wide range of stakeholder groups towards sustainable bioenergy development on a global level. The position and vision of stakeholders on bioenergy sustainability is important for the deployment and contributions of bioenergy towards sustainable pathways. Six methodological steps were carried out. First, stakeholders were classified in one of seven stakeholder groups.

These groups include academia and consulting, NGOs, policy makers, biomass users for energy, general public, and biomass users for non-energy purposes. Second, the role of each group in relation to bioenergy was identified. For example, the biomass producers are actors who supply feedstocks and are involved in the cultivation, harvesting and collection, storage and logistics of biomass. The biomass users for bioenergy and for other purposes are stakeholders involved in the bioeconomy sectors or in the supply chains of biomass for various purposes: logistics, pre-treatment, and conversion of feedstocks to products of the bioeconomy. Third, a comprehensive consultation was carried out. The consultation included an online questionnaire, roundtable dialogues, and interviews to examine their stated awareness and opinions on bioenergy development, and their view on drivers and barriers to future sustainable development. Fourthly, a data analysis was performed to reveal the position and vision of the stakeholder groups. In addition, a comparison of interests and influence of the stakeholder groups was completed based on the consultation results. Finally, recommendations were provided how to gain and enhance support for sustainable bioenergy development.

All stakeholder groups confirmed their awareness of bioenergy development and most stakeholders had in general a positive view of the bioenergy sector. All stakeholder groups also agreed that the general public was less aware of and not sufficiently involved in bioenergy development. Internet and social media were the most consulted sources of information but least trusted, while scientific studies were the most trusted but least used information source. Agricultural residues, energy crops cultivated on marginal or degraded land, and forestry residues were widely accepted by the stakeholder groups as feedstocks for bioenergy production, whereas use of agricultural land was viewed critically. The stakeholders generally supported bioenergy development if jointly agreed sustainability requirements were to be met.

The results of the stakeholder consultation showed that as awareness of bioenergy of the *general public* was low, the general public was not interested in bioenergy development. *Environmental NGO groups* on average expressed an interest in bioenergy (when bioenergy was among the larger sectors using biomass feedstocks). Some environmental NGOs that participated in the consultation showed a clear position about bioenergy development with some having concerns about environmental impacts of feedstock sourcing and mobilisation for bioenergy. Some of them had a very critical view towards bioenergy and saw a limited bioenergy potential. Other associations representing the *biomass producers and bioenergy industry* were more neutral and supportive of bioenergy. Certain *biomass users for other purposes* than bioenergy, such as biochemical and biomaterial stakeholders emphasised concerns over resource competition between bioenergy and their own sectors. *Biomass producers and biomass users for energy* were generally interested in bioenergy and they supported bioenergy development. The *biomass users for energy* are direct agents working on bioenergy, and it was as anticipated that their interest in bioenergy was high. The *academia and consulting group* showed a high interest in bioenergy development, which can also be explained by bioenergy being their working field. The p*olicy maker group* had the most important role in designing energy policies which influence the bioenergy development.

The stakeholders acknowledged the important role of effectively disseminating scientific information as an influencing factor on the position of stakeholders towards bioenergy. They also found that in order to achieve sustainable development of the bioeconomy, and gaining and enhancing support for the bioenergy sector, mandatory (legally binding) sustainability requirements should be applied to all types of biomass and regardless of end uses. Many stakeholders also emphasised that all relevant sectors using biomass should work on market conditions to create a level playing field. They stated that this is crucial to change the position of stakeholders and gain more social acceptance of bioenergy. Transparency in demonstrating compliance with sustainability criteria was also an expected pre-condition to enhance support for bioenergy (and ultimately the bioeconomy) in the long term.

Chapter 4 assessed sustainable biomass export potentials from parts of Brazil, Colombia, Indonesia, Kenya, Ukraine and the United States by applying a number of relevant sustainability criteria. Availability of low-cost sustainable biomass in the EU might be limited and not be sufficient to meet increasing demand; therefore, exploring the option of importing sustainable biomass is imperative for the years to come.

A comprehensive methodology was applied to estimate sustainable biomass export potentials. The first step involved the selection of the case study regions of the highest biomass potentials within different countries, and the potential mix of biomass resources was analysed per region. In the second step, the *technical potentials* were calculated based on production statistics of agricultural and forestry products combined with residue-to-product ratios, or from literature on the production of solid biomass or residues per hectare. In the third and fourth steps, *sustainable potentials and sustainable surplus potentials* were calculated considering per region and per feedstock, based on literature and local expert opinions. Percentage of primary and secondary residues used locally was subtracted from the sustainable potential to form the sustainable surplus potentials. In the fifth step, the *sustainable export potentials* were calculated. Solid biomass needs to be pre-treated and densified before it can be transported across long distances. As default pre-treatment technology, pelletization of woody and agricultural biomass was assumed since this was the pre-treatment technology most commonly used for solid biomass. The future pelletisation capacity was estimated by analysing current capacities (if any) and growth curves of production capacity in the respective countries, and by considering potential capacity growth rates. In the final step, the costs of delivering solid biomass to the import point, port of Rotterdam, as well as the GHG emissions along the supply chains were calculated. Cost supply curves and GHG emission curves were generated to account for differences between different supply regions and feedstocks.

The assessment indicated that, except for the US, pellet markets in the sourcing regions were largely undeveloped. The export potentials depended strongly on pellet mill capacity and assumed growth rates in the pellet industry. Results showed that the US, Ukraine, and Brazil offered the highest biomass export potentials. In the Business As Usual (BAU) 2030 scenario, up to 204 PJ could potentially be mobilized, in the High Export (HE) scenario this could increase to 1,423 PJ, with 89% of the potentials being available for costs ranging from 6.4 to 15 €/GJ. These potentials meet the EC requirements for 70% GHG emission reduction for heat production electricity generation as currently set in the RED II. However, the total sustainable export potentials do not reflect the net possible import potentials to the EU. Biomass could be imported to other demanding countries notably Republic of Korea, Japan, and China where less strict sustainability requirements are applied, that are proximate to the sourcing regions. Vice versa, biomass could also be imported from other regions than the ones investigated.

Chapter 5 investigated possible sustainability gaps in the Renewable Energy Directive Recast (RED II) and proposed effective sustainability criteria for bioenergy. Sustainable bioenergy is promoted in various energy policies and was emphasised in the RED II. However, the adoption of the RED II still raised sustainability concerns. A review and assessment of sustainability criteria and sustainability verification defined in the RED I and RED II were carried out. Certain environmental criteria were included for biofuels in the RED I, and some new and additional environmental criteria were defined in the RED II for the whole bioenergy sector. Social and economic criteria were not established in neither the RED I nor the RED II. An investigation of national legislations and voluntary schemes was also implemented to reveal coverage and comprehensiveness of sustainability criteria for bioenergy, and identified how far they meet or go beyond the definitions of the RED II. Based on the findings of the assessment and investigation, effective sustainability criteria for the whole bioenergy sectors were identified to respond to sustainability concerns of bioenergy which go beyond the definitions of the RED II.

A consultation was carried out with contributions of industrial stakeholders, policy makers, and relevant experts. For the consultation, a questionnaire was developed and sent to a number of selected stakeholders via an online survey and interviews. The aims were to validate the selection of the effective sustainability criteria for bioenergy; b) to investigate the updates of sustainability frameworks in the Member States receive their opinions and vision on the adoption of the RED II, and its transposition to national legislations.

The assessment acknowledged the role of the RED II to safeguard sustainable bioenergy supply in the near future. However, the sustainability criteria defined in the RED II still bear some sustainability risks. The RED II lacks clarifications and sustainability criteria relevant for imported biomass feedstocks. The transposition of sustainability criteria defined in the RED II to national legislation remained a challenge for Member States without clear and detailed guidance for certain sustainability criteria and accompanied indicators.

Based on sustainability concerns of stakeholders, studies on remaining gaps of the RED II and bioenergy in general, inclusion of sustainability criteria by individual voluntary schemes, a number of effective sustainability criteria were proposed. The proposed effective sustainability criteria enhance sustainable land use, biodiversity and ecosystem conservation, whilst also addressing an efficient use of resources, rights for workers and local community in sourcing regions. The effective sustainability criteria for waste and residues include GHG emission reduction, carbon stock preservation, protection of water, soil and air, and labour rights. In comparison with waste and residues, the effective sustainability criteria for agricultural biomass are additional, including biodiversity conservation, prevention of high iLUC risks, land rights, and food security. The effective sustainability category are most stringent and comprehensive for forest biomass which further include SFM, a LULUCF reporting, and risk based approach. A reporting of cascading use of biomass was considered but it does not necessarily act as an effective sustainability criterion since a consistent definition was not yet agreed. All types of sustainable biomass need to be verified by a chain of custody system (mass balance).

The results also showed that certain national support schemes and voluntary schemes that establish stringent and comprehensive sustainability criteria were deemed overall effective to safeguard sustainable bioenergy. Policy makers, scheme owners and sustainability practitioners were recommended to coordinate discussion and agreements on various sustainability aspects at the EU level. These aspects include clear definition of waste and residues, and cascading use of biomass; measurements of iLUC. Finally, it is important to demonstrate sustainability that sustainability criteria established in voluntary certification systems are benchmarked against the sustainability criteria defined in the RED II. The competent voluntary schemes should be then recognized by the EC.

6.2 ANSWERS TO THE RESEARCH QUESTIONS

a. What are different concerns raised by stakeholders regarding environmental, socio-economic impacts of bioenergy production and consumption? What are their position and vision towards sustainable bioenergy?

Concerns of stakeholders on bioenergy sustainability as well as position, and vision of stakeholders towards bioenergy are important for the sector to further develop towards sustainable pathways. Although national governments and the bioenergy sector are making efforts to safeguard sustainable bioenergy supply, certain concerns remain amongst stakeholder groups on bioenergy production and consumption. The shared concerns of different stakeholders at the global level, as investigated in Chapter 3 and to some extent in Chapter 5, are presented below.

Environmental concerns: The largest shared concerns among stakeholders related to risks of unsustainable forest management, impacts of land use change, impacts on biodiversity, and low GHG emission savings. The stakeholder groups including NGOs, academia and consulting, and biomass users for non-energy purposes raised the issue of land use change impacts. They also highlighted that monitoring guidance of (i)LUC particularly in sourcing countries needs to be provided by policy makers to avoid high iLUC risks. The NGO group paid additional attention to impacts of harvesting biomass feedstocks on nature conservation, in particular disturbance to primary forests and wetlands. The biomass users for non-energy purposes group and the NGO group also mentioned their skepticism about low GHG emission savings.

Social and economic impacts: Many stakeholder groups acknowledged contributions of the bioenergy sector to economic development both in developed and developing regions. Jobs have been created, and a positive impact on economic growth had been observed in Europe, the US, South America, and some countries in Asia and Africa. Regarding social impacts, several stakeholders were uncertain that land rights and worker rights including child labour were fully addressed in sourcing regions. Non-compliance with land rights and worker rights may lead to potential negative impacts to local community.

Transparency of sustainability reporting and verification: Sustainability certification and third party verification are important tools to safeguard sustainable bioenergy supply. According to many stakeholder groups, there was still lack of transparency in reporting sustainability compliance, and it was difficult to trace back certified bioenergy. Certain voluntary schemes established sustainability criteria only covering legal requirements that have not fully addressed sustainability concerns; therefore, several stakeholder groups were skeptical that bioenergy sustainability was safeguarded.

Limited sustainable feedstocks and feedstock competition: Whilst bioenergy development was supported by many stakeholders of the academia and consulting group, the other groups including policy makers, biomass producers, certain biomass users for other purposes, and NGOs expressed concerns of harvesting bioenergy crops and forest biomass for bioenergy. They mentioned that these biomass sources should be prioritised for non-energy purposes including the biochemicals and biomaterial sectors. These stakeholders stated that feedstock competition needs to be avoided among the bioenergy sector, the biochemicals, and the biomaterial sectors. Within the groups

NGOs and general public, competition between bioenergy and food was considered an important issue that needs to be tackled.

The position of stakeholder groups identified in Chapter 3 varied widely. Nevertheless, the general view of all stakeholder groups was still positive for bioenergy development. Important aspects are summarised below.

Interest and influence: The general public had little interest and influence in the bioenergy sector because they are generally not aware of bioenergy development. Policy makers were considered to have important roles in bioenergy development, and therefore the information delivered to them was important to design related policies. The consulted NGOs were considered strong advocates on their interested topics, and their information could change position of other stakeholder groups. The academia and consulting group was considered experts delivering important information about bioenergy development. They could have influence on position of other groups but they were not considered active in communication with other groups.

Current sustainability concerns and awareness of bioenergy development: In Chapter 3, these concerns and awareness had shown to have impact on the position of the stakeholder groups. Therefore sustainability concerns of bioenergy should be publicly debated with involvement of various stakeholder groups. The stakeholder groups who are interested in bioenergy should be aware of bioenergy development. Unbiased information about bioenergy should be disseminated to these interested groups. The bioenergy stakeholders should carefully recognise the sustainability concerns and recommendations of the interested stakeholder groups for moving towards the sustainable pathways.

Key aspects to decide position of stakeholders to whether support or disapprove bioenergy: One of the key aspects was the implementation of additional sustainability criteria to avoid sustainability risks, which include reduction of GHG emissions, SFM, protection of natural resources, conservation of biodiversity, worker rights, and land rights. Demonstrating sustainability compliance and transparency was also found an important aspect to external stakeholders. According to most of the stakeholder groups, sustainability compliance and transparency is important to prove that the bioenergy sector implements good practices to safeguard the environment, and in the meantime assure social compliance, and economic contributions of bioenergy projects, particularly in less developed regions.

The vision of the stakeholder groups was revealed in Chapters 3 and 5. The stakeholder groups shared their vision for the short and medium term as well as for the long term of bioenergy development.

In the short and medium term, the majority of the stakeholders groups confirmed the contributions of bioenergy to energy security at national level. Many supranational stakeholders additionally emphasised the contributions of bioenergy to climate change mitigation. These stakeholders also clarified that the bioenergy sector needs to response to the most urgent sustainability concerns raised by stakeholder groups including the NGOs and general public. Information about bioenergy development was still divergent and confused external stakeholders. Therefore, dissemination of unbiased findings on benefits (and impacts) of bioenergy development and solutions that tackle existing sustainable concerns would help the bioenergy sector to gain support.

According to many stakeholders, demonstrating compliance with sustainability criteria was a good way to tackle existing sustainability impacts. However, measuring sustainability criteria should be considered at local and regional level due to geographical, social, and economic differences. Certification by voluntary schemes was considered a sufficient proof of sustainability compliance that could ultimately stimulate acceptance of general public for bioenergy development and their willingness to pay for bioenergy use. However, certain stakeholder groups including biomass users for other purposes, academia and consulting considered the bioenergy sector uncompetitive. By the time of investigation, 2016-2018, bioenergy price was still high compared to fossil fuel price (but the CO_2 price in the total fossil fuel price is not internalised as for bioenergy price). In addition to tackling environmental impacts and reducing GHG emissions, the bioenergy sector should consider working on technological advancements, particularly the pre-treatment technologies and efficient supply chains to reduce costs. Most stakeholders emphasised that dependence on subsidies and national supports might be a barrier for the bioenergy sector to further development. Establishment of profitable business based on biomass should be the targets of bioenergy stakeholders. In addition, bioenergy market should be fair, competitive, and transparent.

According to most stakeholders, bioenergy end uses depend on regional policies and there were many lessons that other world regions could learn from an advanced region such as the EU for establishing (bio-)energy policies. The EU implemented related bioenergy policies since almost two decades with gradual policy shifts to ensure a better sustainable production and consumption of bioenergy. Policy makers from other world regions could gain experience from the implementation of EU policies to design and implement policies in their own country.

In the long term, many stakeholders underlined the importance of integrating bioenergy in the bioeconomy in which all sectors using the same biomass share vision and strategies of supportive development. Acknowledgement of different position and engagement with external stakeholders to find mutual solutions would help the bioenergy sector grow sustainably.

b. How are sustainable biomass potentials determined in various sourcing regions? What are the resulting sustainable export potentials?

The main exporting regions of solid biomass today are the US, Canada, and Eastern Europe, and it is likely that these regions will remain the largest export regions up to 2030. Beyond 2030, a broadening of export regions towards Latin America, Oceania, and Africa is projected. The supply potential varies substantially between different regions depending on location specific factors. In Chapter 4, six different sourcing regions including Colombia, Brazil, Indonesia, Kenya, Ukraine, and the US were chosen to investigate sustainable biomass potentials, and how these potentials could be mobilised to the EU and other import regions. These regions were selected based on their relevance in current and future export scenarios, their geographic specificities, access to local data, and expert consultation. The regions include existing export regions including the US, Ukraine, and regions that could potentially become export regions including Colombia, Indonesia, Brazil, and Kenya.

There are three (simplified) methodological steps that determine *sustainable biomass potentials* from sourcing regions to the EU (see Figure 6.1). These steps include determination of technical potentials, assessment of various sustainability constraints, and identification of scenario conditions (BAU vs HE). In the BAU scenario, local use and pellet production capacity were the main constraints causing low sustainable export potentials. In the HE scenario, yield increase, better management & practice, reduced local demand that led to larger sustainable export potentials. To estimate the technical potentials, regions in the selected countries were investigated that had both high biomass production, and the necessary logistical infrastructure to export, for example with adequate road infrastructure, railways, and ports. The technical potentials were calculated based on production statistics of agricultural and forestry products combined with residue-to-product ratios (RPR), or from literature on the production of solid biomass or residues per hectare. The sustainable potentials were assessed taking into account sustainability criteria that were considered relevant to the selected regions, while also taking into account local context and specific conditions of biomass supply including sustainable removal rates, and domestic demand. The sustainable potentials (that is determined by applying sustainability criteria) were partly based on regionally specific inputs in some cases, such as the Ukraine and the US. In other case studies, such as Brazil, lack of data required an application of default values for the focused regions. In the BAU scenario, the combined sustainable biomass potentials of all investigated regions were estimated to be 5.0 EJ with sustainability criteria applied (reduced from 7.8 EJ of the technical potentials). In the HE scenario, the sustainable potentials were estimated to be 10.2 EJ (reduced from 14.1 EJ of the technical potentials, see Figure 6.1).

To assess the *sustainable export potentials*, five factors were taken into account: local use; possibilities of mobilisation of sustainable surplus potentials; cost of biomass delivered to EU; strictness of GHG emission reduction (for example 70% or 80% of GHG emission reduction); and also the scenario conditions (BAU vs HE). The sustainable surplus potentials were first assessed after subtracting current and expected future local demand for biomass for material and energy applications, covering industrial and residential utilisation. The sustainable export potentials were determined taking further into account the logistical infrastructure limitations of different transport modes, and construction of pre-treatment facilities. These factors varied per country and had different impacts on the sustainable export potentials. In the existing export regions with a well-established infrastructure, sustainability criteria (and to what sectors they are applied), and the development of other non-energy markets were shown to be the most important factors that determine the sustainable export potentials. For countries that do not have a well-developed infrastructure to mobilise biomass, mobilisation is typically the largest constraint to gain access to biomass potentials. The combined sustainable export potentials of all regions combined was estimated to be 204 PJ in the BAU and 1,423 PJ in the HE scenario.

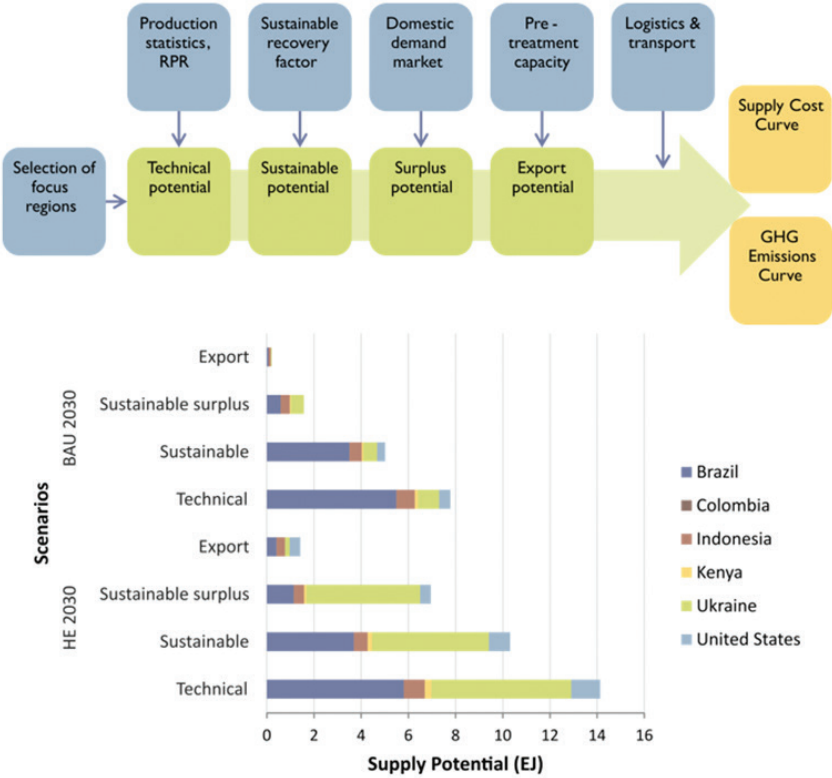


Figure 6.1. Method to determine biomass potentials and case study results

Results for the six case studies showed that the sustainable export potentials of lignocellulosic biomass were limited compared to the technical potentials, ranging between 3 to 10%. However, Chapter 4 also shows that sustainable export potentials may increase in most countries in the future, particularly in the HE scenario. In certain regions, the poor conditions of infrastructure, logistic facilities, and pre-treatment capacity limited the availability of lignocellulosic biomass to be mobilised for export. These barriers furthermore resulted in higher costs and higher GHG emissions in regions with poor infrastructure. If these challenges were to be overcome, costs and GHG emissions could be reduced, and access to feedstocks in remote regions could be achieved, leading to higher export potentials available, with more competitive costs and lower GHG emissions. Also, in the cases of Brazil and Ukraine, if barriers to mobilisation would be mitigated, large sustainable export potentials would become available.

The US was the biggest exporter of biomass feedstocks to the EU by the time of research (2015-2017). In this research, the sustainable potentials of the US were estimated to decrease to almost zero in the BAU scenario by 2030 when assuming that sustainability criteria were to be applied to the whole forest sector (instead of only the pellet sector). Such assumptions were not made in the other case studies. When sustainability criteria were only applied to the pellet sector, the export potentials from the South-East US could become the largest of all studied regions, increasing up to 452 PJ in the HE scenario by 2030. Compared with the current total import of 360 PJ of wood pellets to the main import countries including the UK, Netherlands, Denmark, and Belgium in 2016,[51] the US could supply up to 125% of the total extra-EU imports of wood pellets to the EU in the HE scenario.

The feasibility of importing sustainable biomass to the EU was found to be mainly limited by costs and requirements of GHG emission savings in the RED II from 2026 onwards. The estimated supply chain costs of biomass export from the different sourcing countries to the EU were compared with the market price of wood pellets in the Netherlands between 2009 and 2015.[231] The historic cost ranges were between 6.3 €/GJ to 8.0 €/ GJ, which was considered representative for the international wood pellet market. In the HE 2030, 89% of the potential was estimated to be available at costs ranging between 6.4 to 15 €/GJ delivered to Rotterdam port. These results indicated that the feasibility of importing lignocellulosic biomass to the EU was limited by costs. The costs of solid biomass from Ukraine were relatively low, ranging from 6.4 €/GJ to 11.8 €/GJ, which could be mainly explained by the relatively short transport distance from Ukraine to the port of Rotterdam. Colombia is three times farther from the Netherlands than Ukraine but costs from Colombia were calculated to be between 6.5 and 9.2 €/GJ mainly as a result of cheap feedstock and low pellet-production costs. With sustainable biomass supplied from the US to the EU, the costs range between 7.4 €/GJ to 35.0 €/ GJ; the high end of the range was the result of the increased cost of collecting residues when approaching the maximum potentials, resulting in 90% of the potentials ranging between 7.4 €/GJ and 15.0 €/GJ, and the other 10% ranging between 15 €/GJ to 35.0 €/ GJ. As a result of long-distance intercontinental transport, as well as expensive inland transport, Brazil and Indonesia showed higher cost ranges, from 10.8 €/GJ to 15.3 €/ GJ, and 11.6 €/GJ to 16.2 €/GJ respectively. However, this thesis did not investigate the impacts of economies of scale, improved infrastructure and advanced pre-treatment technologies, all of which could lower these costs to some extent. Also, in case of higher CO_2 prices and sustainable biomass resources getting increasingly scarce in the EU, the ability to pay for biomass by EU users might also increase.

The feasibility of importing sustainable biomass to the EU was also limited by the requirements of minimum GHG emission savings as applied in the RED II. Supply chain emissions of the sustainable import biomass potentials were mainly caused by fertiliser use in some cases, and local and international transport in other cases. In consideration of the existing 70% GHG emission reduction requirement as set in the RED II for the period 2021 to 2025, 100% of the total sustainable export potentials in the BAU 2030 and HE 2030 would be available to export to the EU for heat and electricity generation. In the HE scenario, higher sustainable export potentials were available with contribution of large biomass volume from the US as interlinkages between the US industries using forest biomass became highly efficient. However, once the threshold of GHG emission reduction is increased up to 80% from 2026 onwards (as set in the RED II), only the potentials in the US, Ukraine, Colombia, and part of the potentials in Kenya and Brazil would meet these stricter sustainability requirements. About 60% and 80% of sustainable export potentials could be mobilised for heat and electricity generation respectively. The share of the potentials that does not meet these thresholds would not likely be mobilised for export to the EU in the future. However, with the decarbonisation of the transport sector, GHG emissions in the supply chains may also decrease over time. Likewise, development of better infrastructure and advanced pre-treatment methods of biomass could reduce supply chain emissions. Both factors could increase the share that meets the 80% threshold.

Despite the constraints, it can be concluded that substantial sustainable biomass export potentials exist, and one of the biggest constraints is to mobilise these potentials. The establishment of efficient supply chains is therefore important for sustainable biomass mobilisation.

As a result of limited data availability and difficulties in consulting local stakeholders regarding national policies and local markets in the exporting regions, results of the estimated export potentials contain a large degree of uncertainty. The largest uncertainties are caused by residue-to-product ratios, sustainable recovery factors, and local biomass demand. Thus these results need to be interpreted with care. Given that sustainability criteria and reporting requirements are currently being implemented or will be established in certain countries (for example in Japan and Republic of Korea), the market price and global trade of solid biomass might change accordingly from one country to the others. Biomass feedstocks that do not meet strict sustainability criteria required in one country might be sold to other countries with no or loose sustainability criteria requirements, i.e. leakage effects. More research is necessary to improve the understanding of future global trade of solid biomass for the bioenergy sectors between different countries.

c. What are effective sustainability criteria for bioenergy, taking into account wider sustainability concerns and practical implementation issues?

To safeguard sustainable bioenergy, effective sustainability criteria that can be implemented and verified in practice are needed. Such effective sustainability criteria should be sufficiently strict and comprehensive to mitigate adverse sustainability impacts over the whole supply chain, address stakeholder concerns, and at the same time avoid becoming an unnecessary burden or barrier to bioenergy development. A number of effective sustainability criteria were identified based on a comparison of the updated sustainability criteria in the RED II, existing voluntary schemes, national legislation, scientific literature, and stakeholder consultation identified in Chapters 3 and 5. It was found that the binding sustainability criteria in the RED II are not sufficiently comprehensive and strict to be considered effective by many stakeholders. The effective sustainability criteria proposed in this thesis distinguish between various feedstock types: waste and residues, agricultural biomass, and forest biomass.

The criteria for *waste and residues* in the RED II include GHG emission savings and require monitoring or management plans that address soil quality and soil carbon impacts if supplied from agriculture. In order to be effective, however, the criteria for *waste and agricultural and forest residues* were proposed to include GHG emission savings; carbon stock preservation; protection of water, soil and air (which also addresses soil quality and soil carbon impacts); and labour rights.

The criteria *for agricultural biomass* should include, next to the criteria for waste and residues, biodiversity conservation, prevention of high iLUC risks, land rights, and food security. The proposed biodiversity conservation criteria (see Chapter 5) are more stringent than defined in the RED II, whilst land rights and food security are not included in the RED II.

The criteria and requirements are more comprehensive for *forest biomass*: in addition to the previous criteria, they further include SFM principles, a LULUCF-reporting requirement and a risk-based approach (RBA). The SFM principles are more stringent whilst the LULUCF reporting requirement is similar to the definitions in the RED II. The RBA was recommended in the RED II, and it should be used to assess all forms of available evidence that indicates compliance with the SFM and carbon stock criteria when sustainability certification is not available at the sourcing area level.

Reporting resource efficiency of biomass was also considered for all types of biomass, but it was not deemed effective since there has been no agreement yet on a consistent definition nor how it can be effectively be implemented.

These sustainability criteria are considered adequate to supplement the RED II criteria to better respond to sustainability concerns by stakeholders, and assure sustainability of bioenergy. It is expected that these proposed criteria are effective and could be widely implemented. A key aspect is that all identified effective sustainability criteria have already been implemented and verified in practice through one or several voluntary certification schemes. Some voluntary schemes have already established comprehensive sustainability criteria, although only for certain biomass feedstocks. Also, the consultation with various stakeholders has validated the selection of these effective sustainability criteria. Member States, which aim to establish comprehensive sustainability criteria for bioenergy in their national legislation, are recommended to consider these effective sustainability criteria - the additional sustainability criteria identified in this PhD thesis in addition to the sustainability criteria defined in the RED II.

Another aspect of "effective" is how criteria can be implemented, verified and monitored. This thesis has focused on the use of voluntary certification schemes as the main system to inclusion of sustainability criteria defined in national legislations and the RED II. Voluntary schemes can in principle accommodate both specific additional requirements in national legislations (and be used to demonstrate compliance), and (also) go beyond what is required by law to meet additional stakeholder concerns. Also, voluntary systems can be adapted more easily and rapidly than for example, a renewable energy directive. Therefore, using widely recognised voluntary schemes is a way forward to demonstrate compliance with the effective sustainability criteria that are relevant for various end-uses (such as transport biofuels, heat, and electricity) using the same feedstocks.

Notwithstanding the flexibility of voluntary schemes to deal with differing national legislations, harmonisation of sustainability criteria established in various national legislations and voluntary schemes is considered an important approach to implement effective sustainability criteria in practice. In Chapter 2, harmonisation possibilities were investigated for a number of reasons. It is still an administrative burden and costly to demonstrate compliance with sustainability criteria and reporting requirements that vary between countries, feedstock types, and end-uses. Various national legislations and laws have defined sustainability criteria that are different for biofuels, and solid biomass used in the heat and electricity sectors. This makes it challenging for economic operators and sustainability auditors to demonstrate sustainability compliance. In addition, leakage might occur when unsustainable biomass is shifted to countries with loose sustainability criteria and reporting requirements, whilst costly and sustainable biomass is used in countries with more comprehensive and stricter sustainability criteria. Furthermore, the selection and comparison of relevant voluntary schemes to demonstrate sustainability compliance was also challenging. Many voluntary certification schemes defined their own sustainability approaches to respond to different societal concerns of using biomass for production of bioenergy, and for other bio-based materials. Some of these voluntary schemes established comprehensive sustainability criteria for certain biomass feedstocks, and these sustainability criteria were considered sufficient to assure sustainability compliance of those feedstocks. Several other voluntary certification schemes only covered sustainability criteria to respond to binding sustainability compliance defined at EU or national level.

Given the implementation of the RED II, clear definitions for waste, residues, and agricultural feedstocks are needed for voluntary scheme owners, certification bodies, and auditors. In particular, comprehensive LUC measurements and iLUC estimation are needed to ensure sustainable biomass mobilisation. While Member States are not allowed to implement additional or more stringent sustainability criteria for biofuels used in transport to protect the internal market, this rule does not apply if its end-use covering electricity and heat. This may lead to complexity in defining a threshold for the heat and electricity plants, and in selecting relevant sustainability criteria at national level. The results of Chapter 2 showed that certain sustainability criteria, that were clearly defined and successfully implemented in practice, could be harmonised. Those were SFM criteria covering biodiversity and ecosystem protection, and forest productivity.

Furthermore, “effective” criteria also entail the elements of low costs and low administrative burden for operators. Reconciling these elements with yet more criteria will remain a challenge. A harmonised sustainability certification scheme that takes into account various sustainability concerns and safeguard sustainable bioenergy produced from various feedstocks would be ideal to be implemented at the EU level. By the time of investigation, there was not yet a scheme that cover comprehensive sustainability criteria for all types of feedstocks. If such a voluntary scheme existed, it is still uncertain whether it might be widely used. RSB has been assessed and acknowledged by diverse stakeholders as a competent voluntary scheme, and as shown in Chapter 5 includes the most comprehensive sustainability criteria and clear reporting requirements for agricultural biomass, waste and residues. RSB was also recognised by the EC to certify biofuels. However, in the EU biofuel market, RSB was not widely used for biofuel certification. The comprehensiveness and strictness of sustainability criteria defined in the RSB might be barriers for implementation as more time and resources are needed to carry investigation, which ultimately lead to higher costs of certification. Certification will add complexity in addition to the traditional data collection along the value chains. As biomass typically only provides a very minor part of the income of a forest owner, this means that even more complex schemes will make it even less likely that these schemes will be implemented; unless identical sustainability demands are required for all biomass produced (e.g. also for sawn timber, pulp and paper, and agricultural products).

It is important to note that voluntary schemes are flexible to changes and can be tailored to verify various impacts, therefore they are powerful in their approach to guarantee sustainability. However, how changes should happen and how efficient the voluntary schemes can be, still needs to be determined by discussion and agreements among policy makers, voluntary scheme owners, and sustainability practitioners.

6.3 REFLECTION AND RECOMMENDATIONS

6.3.1 Reflection and outlook on development of sustainability frameworks of bioenergy and the bioeconomy

This PhD thesis has explored possible conditions for the bioenergy sector to move towards sustainable pathways. In this section, we briefly reflect on the past development and future outlook of sustainability governance for the bioenergy sector and bioeconomy at large. In section 6.3.2, we then reflect how the findings of this thesis could be used to guide the future development of the bioeconomy.

When looking at the development of sustainability governance for the increased use of modern bioenergy, there are three main elements that are interlinked in a cycle, and have important roles in shaping the sustainable pathways for bioenergy (see Figure 6.2). These elements include (1) the main sustainability concerns of bioenergy as perceived by various stakeholders, (2) (effective) sustainability criteria that are established and implemented to mitigate the main concerns, while avoiding an unnecessary burden to bioenergy deployment, and (3) the (resulting sustainable) production and consumption of bioenergy.

In the early 2000s, the first cycle started with the growth of modern bioenergy (mainly industrial heat and electricity in North Western Europe). In the period of 2002-2008, in countries such as Belgium, the UK, and the Netherlands, various stakeholders have held discussion on establishing sustainability criteria for bioenergy to address sustainability concerns of bioenergy development. As an example, Belgium established the green certificates promoting electricity production from renewable resources requiring GHG emission reduction in the supply chains and proving SFM for forest biomass.

At the same time, liquid biofuel deployment grew strongly due to national initiatives and by the policy targets set by the 2003 EU Biofuel Directive. This again raised concerns regarding the sustainability of liquid biofuel production. In 2009 some EU-wide binding sustainability criteria for liquid biofuels were defined in the RED I, as a result of, amongst others, stakeholder concerns and inputs. A few years after the RED I adoption, a number of binding sustainability criteria were also established for solid biomass used for heat production and electricity generation in the UK, the Netherlands, and Denmark. These sustainability criteria and their implementation in national legislations and voluntary schemes were assessed by the bioenergy industry, the scientific community, and NGOs, amongst others to identify remaining sustainability gaps. Although sustainability risks were generally considered low for solid biomass mobilised within the EU, negative impacts of solid biomass in sourcing regions in- and outside the EU were reported. By 2018, the RED II was adopted taking into account further sustainability concerns of biofuels and solid biomass, and considering implementation challenges.

Reflecting the implementation of binding sustainability criteria defined in the RED I for biofuels in the period 2009-2020, the impact cycle of these three elements was limited. Considering the adoption of the RED II in 2018 and the implementation of new binding sustainability criteria for the whole bioenergy sector in national legislation as of 2021, the impact cycle of these elements will be larger.

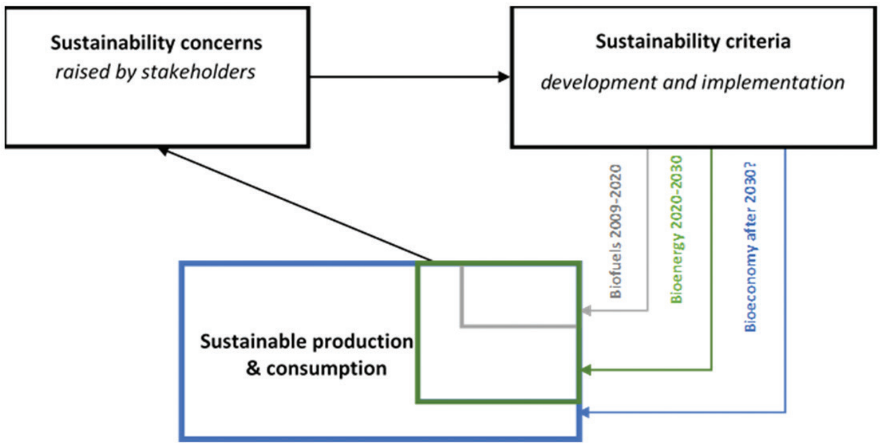


Figure 6.2. Development cycle and key elements of sustainability frameworks for bioeconomy pathways

Looking ahead to and beyond the implementation of the RED II, the use of lignocellulosic biomass mobilised for advanced biofuel production is expected to grow substantially.

The market for advanced biofuels, that are mainly produced from lignocellulosic biomass, is still small at about 0.5 billion litres (bln L) in 2018, which is less than 1% of total biofuel production (153 bln L). On the short term, advanced biofuels are expected to grow to about 1.4 bln L by 2023 contributing to about 1 to 1.5% of total biofuel production.[312] On the longer term however, substantial growth of advanced biofuels is expected, in particular in sectors that have few alternatives for reducing GHG emissions such as aviation and shipping. Lignocellulosic biomass is also expected to become an even more important feedstock for other forms of modern bioenergy, to be widely available at moderate costs, and to cause less competition with food and feed production than energy crops.[313]

Visioning beyond bioenergy development, the use of lignocellulosic biomass for novel materials (e.g. bioplastics and bio-based chemicals) is likely to increase as well. Strategies for the bioeconomy are already established in some national and regional policies.[314,315]

Since the launch of the European Bioeconomy strategies in 2012, the EU bioeconomy has gradually developed with higher value biomass use, higher employment and higher revenues.[316] The entire bioeconomy accounted for 9% of the total economy in terms of employment and revenues in 2014, whilst biomass accredited with more than 25% of total material flows.[317] The bioeconomy development benefits from various European policies that aim to reduce climate change impacts, stimulate sustainable energy, and promote resource efficiency.[314,318,319] Thus, the use of biomass has potential to grow further and expand into new markets. For example, the bioplastics industry is a fast-growing sector with an economic and ecological potential for a low-carbon and circular bioeconomy that uses resources more efficiently. Global production capacities of bioplastics are expected to grow from around 4.2 Mt in 2016 to approximately 6.1 Mt by 2021, and are expected to grow further by 2030.[320]

The growth of the bioeconomy is projected to be largely based on lignocellulosic feedstocks, for example advanced biofuels. With the expected increase of lignocellulosic biomass for various bioeconomy sectors, concerns that thus far have mainly been voiced for the use of lignocellulosic biomass for bioenergy may also arise for other purposes. Various forms of sustainability performance have already been demonstrated voluntarily in many bioeconomy sectors and at multi-output biorefinery level. Sustainability performance remains important for the bioeconomy to grow sustainably.[314] Multi-output biorefineries use the same feedstocks to process bio-based products and bioenergy including biofuels, heat, and electricity, thus the supply chains of the products are comparable.[321] Large multi-out biorefineries that produce biochemicals, biofuels, biomaterials, and also heat and electricity may need to demonstrate compliance with the sustainability criteria of the RED II. With the implementation of sustainability criteria for bioenergy, lessons can be learnt to deliver meaningful sustainability guidance for current and future multi-output biorefineries.

Visioning the global development towards 2050, it is anticipated that there are international and regional initiatives that call for considerations of sustainable pathways of various sectors. Those include the Paris Agreement,[140] the EU development strategies towards low carbon economy and sustainable bioeconomy,[271] and the latest EU Green Deal - a roadmap for making the EU economy sustainable.[322] The EU Green Deal among others, emphasises a climate neutral Europe, a circular economy, protection of ecosystems and biodiversity, and a sustainable transport. To be able to achieve these Green Deal targets, the EU aims for higher cuts of 50-55% GHG emissions by 2030, and a movement towards net-zero GHG emissions by 2050. Also a low and efficient use of materials and resources is highlighted, ensuring products to be recycled and reused. The EU Green Deal additionally addresses main drivers of biodiversity loss, and includes measures to tackle soil and water pollution. The EU Green Deal also underlines sustainable alternative fuels in transport, indicating a promotion of biofuels and hydrogen to be used in aviation, shipping, and heavy duty road transport where electrification is currently not possible.

The conditions to move towards sustainable bioenergy pathways, and the three elements explored in this PhD thesis are relevant not only for bioenergy but also for the bio-economy in the future sustainable roadmaps. The sustainability concerns addressed in RQ1 are appropriate to the sustainability issues highlighted in the EU Green Deal and the Paris Agreement. The sustainable biomass potentials addressed in the RQ2 are also appropriate in a long term sustainable production and consumption context of the bioeconomy. The effective sustainability criteria addressed in the RQ3, which are relevant for the bioenergy sector to demonstrate sustainability compliance, are also appropriate for the EU and other global regions to implement a sustainable bioeconomy and circular economy in the long term, possibly after 2030. It could well be possible that the cycle of the three elements identified in Figure 6.2 will become even larger in the long term, both in terms of end-uses and geographical areas covered.

In the next section, recommendations are formulated for the future use of lignocellulosic biomass in the bioeconomy based on findings in this thesis.

6.3.2. Recommendations

Looking ahead to the development of sustainable pathways of bioenergy and the bioeconomy at large, this PhD thesis provides recommendations for policy makers and for future research. It also includes recommendations for other stakeholders who are involved in the development of bioenergy and other bioeconomy sectors. These recommendations are linked to the three identified main elements in the development cycle of sustainability frameworks: identification of sustainability concerns by stake-holders, development and implementation of sustainability criteria, and realisation of sustainable production and consumption of biomass for energy and materials.

Recommendations related to sustainability concerns:

- Position and vision of stakeholders toward a sustainable bioeconomy

Position and vision of stakeholders are shaped by whether sustainability concerns of various sectors using biomass are properly addressed and mitigated. In addition, awareness of stakeholders on bioenergy will likely evolve further given the ongoing development of the overall bioeconomy, the new strategies towards meeting a 1.5^{o}C target, and the associated aim for a carbon-neutral economy by 2050, but also changing exogenous developments. The awareness will also have impact on the position and vision of stakeholder groups. Whilst the studies identified in the RQ1 aimed to cover the position and vision of global stakeholders towards sustainable bioenergy, main contributions were received from European stakeholders. New studies may seek to further identify the position and vision of more diverse stakeholder groups towards the establishment of a sustainable bioeconomy in the long term. It is also recommended to engage additional, more balanced stakeholder groups. These could involve, amongst others, more stakeholders focusing on socio-economic development and a wide range of stakeholders in export regions.

- Long term policies

The study of position and vision of stakeholder groups in Chapter 3 revealed that economic stimulation, lack of market incentives and unresolved sustainability issues were major barriers to bioenergy development. On the one hand, economic stimulation and incentives have helped the bioenergy sector to grow in the past, but subsidies for bioenergy may lead to conflicts over resource competition among sectors using the same biomass resources. On the other hand, binding sustainability criteria will be soon implemented for bioenergy in the EU as part of the RED II. These criteria are not mandatory for other non-energy sectors using the same feedstocks, which may create an unlevel playing field among bioenergy and other sectors of the bioeconomy. Sustainability concerns should be addressed holistically, thus policy makers may consider establishing sustainability criteria for the whole bioeconomy. At the same time, policy makers may also consider providing more support and incentives for the sectors using the same biomass feedstocks for material uses.

- Bioeconomy development and sectoral collaborations

In this PhD thesis, most external stakeholder groups have expressed concerns on bioenergy development. They considered a development and expansion of sustainable biomass supply chains important for the growth of the entire bioeconomy in the long-term. The consulted stakeholders also recommended all bioeconomy stakeholders to address solutions for mobilising sustainable feedstocks, advancing processing technologies, and more efficient supply chains. In addition, collaboration among the bioeconomy sectors is very important in view of sustainable pathways.

Regarding the sustainability of biomass supply chains, sustainability criteria for biofuels are required at the EU level, whilst sustainability criteria for solid biomass used for heat production and electricity generation have already been implemented in some EU Member States. Therefore, the involved actors in these Member States have experience to deal with sustainability concerns, sustainability criteria, and proof of compliance with various sustainability requirements through certification. With similar processes and product outputs, the actors of biorefineries and the bioeconomy can learn from experience gained through mistakes and successes of the heat and electricity sector to develop sustainable supply chains, and to demonstrate sustainability compliance against sustainability criteria. The experience gained can help these other sectors to facilitate the sustainability compliance more rapidly and successfully.

Recommendations related to development and implementation of sustainability criteria:

- *(Effective) sustainability criteria for the bioeconomy*

A number of effective sustainability criteria were proposed in this thesis to tackle the remaining sustainability concerns of stakeholders that were not fully addressed in the RED II to assure bioenergy sustainability. To move towards sustainable bioeconomy pathways, these sustainability criteria are also relevant for the bioeconomy sectors using the same biomass feedstocks, for example bio-based materials. However, it is important to take into account the specific characteristics of these sectors. For example, the lifecycle environmental performance of bio-based materials varies substantially depending on its use and end-of-life stages. Additional sustainability criteria might be needed to identify potential risks, and to evaluate environmental and health impacts. Future research is recommended to assess the relevance of the proposed effective sustainability criteria to report sustainability performance in the whole bioeconomy.

- *Trade-offs between quality and quantity of biomass use*

The implementation of sustainability criteria might need to consider trade-offs between the quality and quantity of biomass use. As demonstrated in Chapter 4, if sustainability criteria were to be applied to the whole forest sector in the US, the net sustainable biomass potentials available for export would reduce to zero. When sustainability criteria were applied for only the pellet sector, large sustainable potentials would become available. Also the study on sustainable biomass export potentials for bioenergy revealed that when moving from a 70% (current) to a 80% GHG emission reduction threshold (as of 2026) as set in the RED II for heat and electricity end-uses, the volume of sustainable biomass in the sourcing countries that meet this requirement is reduced substantially. In other words, a slightly higher GHG emission reduction threshold thus could cause a substantial decrease in biomass volumes to be available for bioenergy. And especially if sustainability criteria are applied to all bioeconomy sectors, future research is recommended to investigate what might be optimal trade-offs between quality, in terms of reduced GHG emissions (and other environmental impacts), and quantity of biomass availability for the whole bioeconomy.

- *Recognition of established voluntary schemes*

Voluntary schemes that include transparent certification and sustainability criteria, which are clearly defined and verifiable, have been shown to be a viable tool to demonstrate sustainability compliance. Recognition of voluntary schemes by national authorities may increase the legitimacy of certification, trigger further efficiency of sustainability compliance, and stimulate further implementation of the effective sustainability criteria. Policy makers in Member States and at EU level are recommended to benchmark relevant voluntary schemes and possibly recognise them to certify sustainable biomass and related supply chains. This is a way forward to assure sustainability of the bioeconomy sectors.

- *More comprehensive guidance on the implementation of sustainability criteria, and clear and transparent sustainability performance for all bioeconomy sectors*

Comprehensive guidance on data collection, calculation methods, and the availability of up-to-date default values for relevant bioenergy supply chains from EU scientific institutions such as the JRC is important to guide sustainability practitioners. The consultations with various stakeholders have shown that there was a lack of comprehensive guidance and transparent reporting for involved and interested parties. Policy makers are recommended to develop a better guidance, and clear and transparent reporting requirements for voluntary scheme owners, certification bodies, and auditors involved in the sustainability certification.

- *Allocating impacts over energy and materials*

Regarding sustainability performance in the bioeconomy sectors, pending questions remain on how to allocate impacts between bioenergy and other outputs of biorefineries. For example, in the RED II, emission allocation and benefits of processing lignocellulosic feedstocks to multi-output products are based on energy allocation. However, multi-output biorefineries include complex biorefining processes with various outputs and diverse functions that also include material uses. The RED II, as an energy directive, does not provide solutions to properly deal with multifunctionality of materials in multi-output biorefineries, as it only allocates on energy content. A clear guidance on how to demonstrate compliance is still lacking for multi-output biorefineries that might need to comply with sustainability criteria defined in the RED II. It is therefore recommended to develop methods at the EU level to deal with multifunctionality that are more suitable for multi-output biorefineries producing bio-based materials and bioenergy.

- *Development of a holistic sustainability framework for the bioeconomy*

Sustainability criteria and sustainability compliance might need to be considered for the whole bioeconomy in the long-term policy context. The EU wide environmental sustainability criteria are binding for bioenergy as of 2021. Companies using that use the same feedstocks but do not produce bioenergy may choose to cover environmental, social-economic aspects on a voluntary basis, for example by using various voluntary schemes. It is expected that lignocellulosic feedstocks will be increasingly used for energy and materials. Thus, further research is recommended to develop a harmonised, holistic framework for energy and materials to demonstrate sustainability performance in the entire bioeconomy, and guide the biorefinery (and wider bioeconomy) stakeholders to better demonstrate sustainability performance.

In addition, lessons have been learnt from the implementation of sustainability criteria for solid biomass in the Member States to the establishment of EU-wide binding sustainability criteria in the RED II. These lessons can be used by other bioeconomy stakeholders. For example, for implementing sustainability measures at biorefinery level; and possibly for the whole bioeconomy in the future.

Recommendations related to sustainable production and consumption:

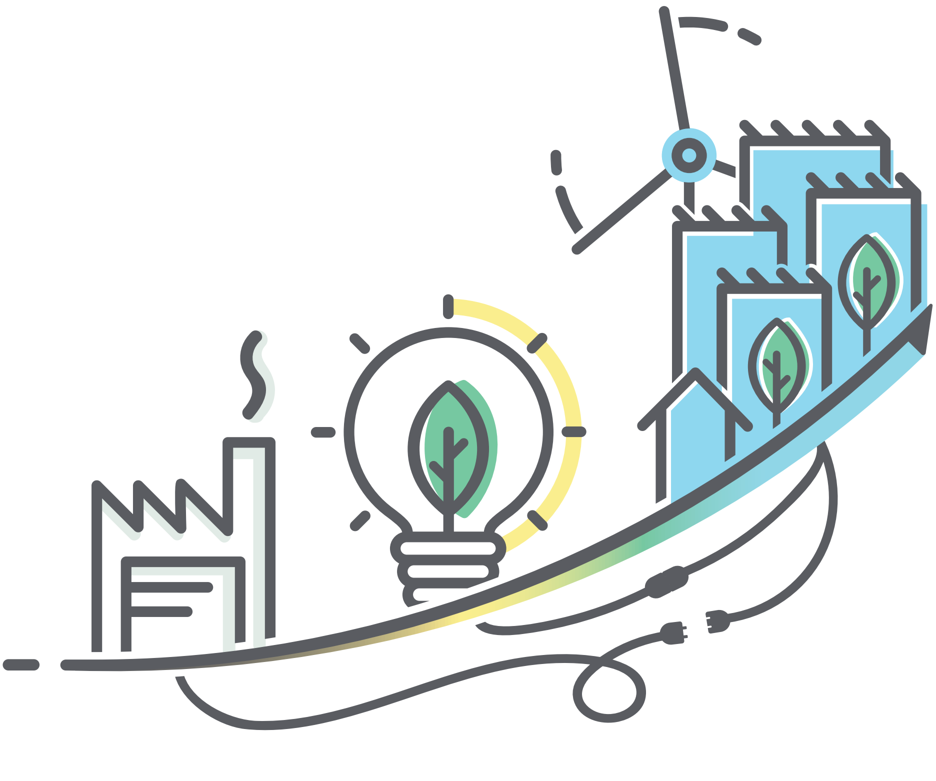
- Further method development to determine net sustainable export potentials

In Chapter 4, a comprehensive method was developed that involved twelve steps to assess net sustainable biomass export potentials. It aimed for a thorough investigation of sustainable biomass sourcing potentials in which relevant sustainability criteria were applied and local demand was considered having a priority over export. Overall the method worked, but there are several points for further improvement.

Data collection was carried out through desk study combined with field trips, and interviews with local stakeholders. This type of data collection was a good initial approach, but should ideally be complemented with spatially explicit studies that allow for a more detailed assessment while taking into account location specific socio-economic and environmental impacts, and potentials. For the case studies investigated in Chapter 4, not all required data was available, and as the collected data was disaggregated in nature, certain references and assumption had to be used. These included assumptions on access to feedstocks, location and construction of the pellet plants, and transport facilities and modes. The potentials were considered at state and regional levels, but in reality, there are large potential differences within states of a country. In addition, priority for local demand was not always applicable when there is no local market demand, as was partly assumed for the US case study. The final sustainable net export potentials should be considered first order estimates, which should be better improved and further verified in future studies.

The selection of sustainability criteria was based on the existing criteria in the RED I and some additional socio-economic criteria that were considered relevant for the local context in each case study. More comprehensive sustainability criteria, which go beyond the definitions in the RED II, might also be needed to further mitigate negative impacts. Chapters 4 and 5 have shown challenges to measure environmental and social aspects in sourcing regions, particularly in countries where national laws and regulations for specific criteria have neither been established or not strict enough to assure sustainability, or are not sufficiently enforced. The proposed effective sustainability criteria in Chapter 5 could be used as a reference to better response to various sustainability concerns of stakeholder groups as identified in Chapter 3. Therefore, future research is recommended to consider a more thorough assessment of relevant sustainability criteria taking into account local conditions in sourcing regions; and identification of barriers and gaps of means to verify and monitor compliance with these criteria. A comprehensive impact assessment of biomass potentials and mobilisation of sustainable biomass potentials to the bioeconomy in the long term may benefit the bioeconomy stakeholders, investors, and policy makers in designing relevant policies.

- Extension of temporal and geographical scope to investigate sustainable biomass trade
Due to time and resource constraints, research on sustainable potentials and sustainable export potentials of lignocellulosic biomass in this thesis was limited up to 2030, and to six potential sourcing regions outside the EU. Despite these constraints, the results in Chapter 4 showed that substantial sustainable biomass export potentials exist, especially in the US, Ukraine, and Brazil, and that one of the biggest constraints is to mobilise these potentials. Therefore, establishment of efficient feedstock supply chains are important for sustainable biomass mobilisation. In addition, unexplored potential sourcing regions with large technical biomass potentials such as Canada, Mozambique, and Vietnam may also possess significant sustainable export potentials. Thus, it is recommended to extend the geographical scope to other promising sourcing regions to achieve a better bottom-up picture of the possibilities of sustainable biomass trade. Also, given the longer-term ambitions, the temporal scope should be extended, for example assessment up until to 2050 (and beyond) are needed.



7

Samenvatting

PADEN VOOR DUURZAME BIO-ENERGIE: Voorwaarden voor vooruitgang

Bio-energie speelt een belangrijke rol in de aanpak van klimaatverandering en vermindering van de afhankelijkheid van fossiele brandstoffen. Bio-energie heeft een belangrijke grote rol in de transitie van de energie sector, die nu nog gedomineerd wordt door fossiele brandstoffen, naar een hernieuwbaar en klimaatneutrale energievoorziening in 2050. Nationaal en internationaal beleid voor hernieuwbare energie, hebben al gezorgd voor een sterke ontwikkeling van moderne bio-energie, waaronder elektriciteit, warmtevoorziening en biobrandstoffen. Deze ontwikkeling heeft ook geleid tot een sterke groei van internationale handel in vaste biomassa en vloeibare biobrandstoffen tussen regio's met een hoge energievraag, maar een beperkt biomassa-aanbod en regio's met een overschot aan biomassa.

Ondanks dat de rol van bio-energie in de energietransitie wordt erkend, heeft de groei van moderne bio-energie en internationale biomassahandel ook geleid tot bezwaren over de nadelige effecten van bio-energie onder stakeholders. Zo zijn er zorgen over de beperkte broeikasgasreductie van slecht presterende bio-energiesystemen en gebrek aan duurzaam bosbeheer in gebieden waar biomassa wordt geproduceerd. Daarnaast is er kritiek over de negatieve effecten op biodiversiteit, bodem en de mogelijke negatieve sociale- en economische effecten van bio-energie. Het laatste geldt met name voor regio's waar biomassa wordt geproduceerd voor export. Er is tot nu toe nog onvoldoende onderzoek gedaan naar de productie en mobilisatie van duurzame biomassa in deze internationale productieregio's van biomassa. Hierdoor bestaat onder bepaalde stakeholders het beeld dat de beschikbaar van duurzame biomassa voor energiedoeleinden zeer beperkt is en de twijfel of bio-energie wel duurzaam geproduceerd kan worden.[309,310] Om aan deze bezwaren tegemoet te komen zijn er al diverse maatregelen genomen die de duurzaamheid van biomassa moeten waarborgen. Zo zijn er onder anderen duurzaamheidscriteria voor bio-energie geïmplementeerd in wetgeving en vrijwillige certificeringssystemen, en worden "best practices" gestimuleerd. Zo zijn er in de Richtlijn Hernieuwbare Energie uit 2009 (RED I) minimale duurzaamheidcriteria vastgelegd voor het gebruik van biobrandstoffen en andere vloeibare biomassa voor alle lidstaten van de Europese Unie (EU). In sommige lidstaten zijn er ook duurzaamheidscriteria voor vaste biomassa vastgelegd in nationale wetgeving en zijn er vrijwillige industriële initiatieven ontwikkeld. In 2018 zijn in de

RED II de duurzaamheidscriteria voor bio-energie voor de EU uitgebreid met nieuwe duurzaamheidscriteria en worden deze criteria toegepast op alle eindgebruikers (elektriciteit, warmte, transport). Ondanks deze wijzigingen, worden in de RED II niet alle bezwaren over nadelige duurzaamheidseffecten van bio-energie volledig geadresseerd.

Het belangrijkste doel van dit proefschrift is te onderzoeken onder welke voorwaarden de bio-energie sector duurzaam ontwikkeld kan worden. De focus van dit proefschrift ligt op bio-energie uit zogenaamde lignocellulose of houtachtige biomassa. Houtachtige biomassa wordt nu voornamelijk ingezet voor de opwekking van elektriciteit en warmte, maar heeft ook een groot potentieel voor bio-based materialen en geavanceerde biobrandstoffen. De onderzoeksvragen die in dit proefschrift geadresseerd worden zijn:

1. *Wat zijn de verschillende bezwaren die leven onder stakeholders over de milieu-, sociale- en economische effecten van bio-energie? En wat zijn de standpunten en visies ten opzichte van duurzame bio-energie?*
2. *Wat zijn de belangrijkste factoren die het duurzame aanbod van biomassa in verschillende exportregio's bepalen? En wat zijn de resulterende duurzame biomassapotentiëlen die beschikbaar zijn voor export?*
3. *Wat zijn effectieve duurzaamheidscriteria voor bio-energie, rekening houdend met verschillende type eindgebruik, verschillende regio's en bredere bezwaren met betrekking tot duurzaamheid?*

Table 7.1. Overzicht van de hoofdstukken en de geadresseerd onderzoekvragen

	Hoofdstukken	Onderzoeksvragen		
		I	II	III
2	Naar harmonisatie van nationale duurzaamheidseisen en – criteria voor vaste biomassa			x
3	De positie en visie van stakeholders ten opzichte van duurzame bio-energie in kaart gebracht	x		x
4	Overzeese biomassa voor Europese ambities: een raming van de duurzame biomassa potentiëlen beschikbaar voor export uit verschillende landen.		x	
5	Effectieve duurzaamheidscriteria en certificering voor de bio-energie sector in de EU: voor de implementatie van de Hernieuwbare Energie Richtlijn II.	x		x

7.1. SAMENVATTING VAN DE HOOFDSTUKKEN

Hoofdstuk 2 onderzocht de mogelijkheden voor harmonisatie van duurzaamheidscriteria en rapporteringseisen in nationale stimuleringsregelingen voor duurzame energie en vrijwillige initiatieven in landen die vaste biomassa importeren voor warmte en elektriciteit: België, Denemarken, Nederland en in het Verenigd Koninkrijk (VK). Verschillende duurzaamheidseisen op nationaal niveau kunnen resulteren in barrières voor certificering en in handelsbarrières. De resultaten lieten zien dat het mogelijk is om bepaalde duurzaamheidscriteria te harmoniseren voor houtachtige biomassa. Om aan te tonen dat biomassa voldoet aan de eisen kunnen producenten en eindgebruikers van biomassa gebruik maken van meerdere erkende vrijwillige certificeringssystemen zoals SBP, FSC en PEFC, en ook certificeringssystemen die zijn goedgekeurd door de Europese Commissie. Het gebruik van deze erkende systemen kan de kosten en complexiteit van het bewijzen van het voldoen aan de gestelde duurzaamheidseisen verlagen en kan uiteindelijk de handel in biomassa faciliteren. Op korte termijn wordt een geharmoniseerd certificeringssysteem voorgesteld binnen de 4 betreffende landen en vrijwillige initiatieven. Voor de lange termijn wordt aanbevolen om op EU-niveau bindende duurzaamheidseisen te stellen aan vaste biomassa.

Hoofdstuk 3 keek breed naar de positie en visie van verschillende stakeholdergroepen ten opzichte van de duurzame ontwikkeling van de bio-energiesector wereldwijd. Alle stakeholders waren bewust van de ontwikkelingen van bio-energie, en over het algemeen hadden de meeste stakeholders een positieve kijk op deze sector. Internet en sociale media waren de meest gebruikte bronnen voor informatie over bio-energie, maar werden ook als minst betrouwbaar beschouwd. Wetenschappelijke studies werden als meest betrouwbaar beschouwd, maar werden het minst gebruikt als bron voor informatie. De inzet van residuen uit landbouw en bosbouw, en energieteelt op marginale gronden voor bio-energie wordt breed geaccepteerd door stakeholder. Stakeholders zijn daarentegen kritisch ten opzichte van het gebruikt van landbouwgrond voor bio-energie. Bio-energie wordt over het algemeen ondersteund wanneer voldaan wordt aan gezamenlijk overeengekomen duurzaamheidseisen. Ook zien stakeholders dat voor het bereiken van een duurzame bio-based economy en het vergroten van steun voor de bio-energiesector, wettelijke duurzaamheidseisen noodzakelijk zijn die betrekking hebben op alle soorten biomassa, ongeacht het eindgebruik. Daarnaast was transparantie in het voldoen aan duurzaamheidscriteria een belangrijke randvoorwaarde voor het versterken van draagvlak voor bio-energie en op de lange termijn de bio-economy. Veel stakeholders benadrukten ook het belang van het ontwikkelen marktcondities voor een gelijk speelveld voor de sectoren die biomassa gebruiken. Dit is cruciaal om de positie van stakeholders te veranderen en de sociale acceptatie van bio-energie te verbeteren.

Hoofdstuk 4 berekende de duurzame exportpotentiëlen van biomassa uit geselecteerde exportregios. Relevante duurzaamheidscriteria zijn toegepast op relatief laagwaardige biomassastromen voor het verkennen van opties van duurzame biomassa voor import in de EU. De verkenning heeft laten zien dat, op de Verenigde Staten na, houtachtige biomassamarkten (pellet markten) nog grotendeels onderontwikkeld zijn. Het duurzame exportpotentieel worden voor een groot deel bepaald door de beschikbare productiecapaciteit van pellets en de aangenomen groeisnelheid van de pellet industrie. De resultaten lieten zien dat de VS, Ukraine en Brazilië het grootste potentieel hebben voor export. In het Business as Usual (BAU) scenario kan tot 204 PJ biomassa worden gemobiliseerd voor export. In het High Export (HE) scenario loopt dit op tot 1,423 PJ waarvan 89% beschikbaar is voor een kostprijs van 6.4 tot 15 €/GJ geleverd in Rotterdam. Wanneer deze biomassa wordt ingezet voor warmte- of elektriciteitsopwekking, dan voldoet het aan de minimale broeikasgasreductie-eisen van 70% die gesteld worden in de RED II. Er is in deze verkenning echter geen rekening gehouden met mogelijke export naar andere regio's zoals Zuid Korea en Japan waar minder strenge duurzaamheidseisen worden gesteld of waar transportafstanden minder groot zijn.

Hoofdstuk 5 onderzocht de mogelijke hiaten in de waarborging van duurzaamheid van de herziende versie van de Europese Richtlijn Hernieuwbare Energie (RED II) en gaf een voorstel voor effectieve duurzaamheidscriteria voor bio-energie. De resultaten lieten zien dat in de RED II een aantal relevante duurzaamheidscriteria ontbreken voor geïmporteerde biomassa. Ook blijft de transpositie van de RED II naar nationale wetgeving een uitdaging voor lidstaten bij het ontbreken van duidelijke en gedetailleerde begeleiding voor bepaalde duurzaamheidscriteria en de gerelateerde indicatoren. De effectieve duurzaamheidscriteria voorgesteld in Hoofdstuk 5 adresseren duurzaam landgebruik, biodiversiteit en bescherming van ecosystemen, efficiënt gebruik van grondstoffen en hulpbronnen, arbeidsrechten en lokale gemeenschappen in toeleveringslanden. De resultaten lieten ook zien dat nationale subsidieregelingen en vrijwillige certificeringsystemen met strenge en uitgebreide duurzaamheidscriteria effectief bleken in het waarborgen van duurzaamheid van bio-energie. Echter, een aantal definities van criteria moeten duidelijker door de betrokken stakeholders gedefinieerd worden. Dit omvat een duidelijke definitie afval en residuen en cascadering van biomassa. Ook moet de manier waarop indirecte landgebruiksverandering bepaald wordt duidelijker worden. Tenslotte is het voor het aantonen van duurzaamheid van belang dat vrijwillige certificeringsystemen tegen de REDII criteria gebenchmarkt en door de Europese Commissie erkend worden.

7.2 ANTWOORDEN OP DE ONDERZOEKSVRAGEN

a. Wat zijn de bezwaren die leven onder stakeholders over de milieu-, sociaal en economische effecten van bio-energie? En wat zijn de standpunten en visies over duurzame bio-energie?

De grootste gedeelde bezwaren over milieueffecten van de ontwikkeling van bio-energie tussen verschillende stakeholdergroepen zijn de risico's van bos wat niet duurzaam wordt beheerd, effecten van landgebruiksverandering, effecten op biodiversiteit, en lage besparingen van broeikasgasemissies. Aangaande economische effecten van bio-energie erkennen de meeste stakeholders de positieve bijdrage van de bio-energiesector in zowel ontwikkelde als ontwikkelingslanden. Aangaande sociale effecten zijn verschillende stakeholders onzeker dat landrechten en arbeidsrechten, inclusief kinderarbeid, goed worden geadresseerd in alle toeleveringslanden van biomassa.

Ondanks dat de algemene visie positief was, was er een groot verschil in posities tussen de verschillende stakeholdergroepen. Volgens veel stakeholdergroepen is er nog steeds een gebrek aan transparantie in de duurzaamheidsrapportage van bio-energie, worden er maar beperk gebruik gemaakt van duurzame biomassa en moet concurrentie voor biomassa tussen verschillende sectoren van de bio-economie worden voorkomen. De huidige bezwaren en kennis aangaande de ontwikkeling van bio-energie heeft een groot effect op de positie van stakeholdergroepen. De belangrijkste besluitredenen om bio-energie te ondersteunen of af te wijzen zijn: de implementatie van uitgebreide duurzaamheidscriteria die de risico's van bio-energie adresseren en een transparante bewijsvoering dat aan deze criteria wordt voldaan. De visie van de meeste stakeholders bevat een erkenning voor de rol van bio-energie in het verbeteren van de nationale energiezekerheid op de korte en middellange termijn. Een aantal supranationale stakeholders benadrukten verder de rol van bio-energie om klimaatverandering tegen te gaan. Echter, stakeholders gaven ook aan dat de bio-energiesector adequaat moet reageren op de meest urgente duurzaamheidsbezwaren van stakeholdergroepen. Voor de lange termijn benadrukten stakeholders het belang van integratie van bio-energie in een geheel duurzame bio-economie.

b. Wat zijn de belangrijkste factoren die het duurzame aanbod van biomassa in verschillende exportregio's bepalen? En wat zijn de resulterende duurzame biomassapotentiëlen die beschikbaar zijn voor export?

Voor de bepaling van duurzame biomassapotentiëlen in de geselecteerde exportregio's is met vijf factoren rekening gehouden. Dit waren lokaal gebruik, de mogelijkheden tot mobilisatie van duurzame biomassapotentiëlen, de kosten van de biomassa geleverd in Rotterdam, de striktheid van de broeikasgasemissie reductie en de scenario voorwaarden. Verder werden de duurzame exportpotentiëlen bepaald door beperkingen van de lokale infrastructuur van verschillende vormen van vervoer, en de bouw van voorbewerkingsfabrieken. Deze factoren varieerden per land en hadden verschillende invloed op de duurzame exportpotentiëlen. De gecombineerde duurzame exportpotentiëlen van alle regio's was ogenveer 204 PJ in het BAU end 1,423 PJ in het HE scenario.

De duurzame exportpotentiëlen waren beperkt ten opzichte van de technische potentiëlen, variërend tussen 3-10%. In bepaalde regio's beperkten de slechte toestand van de infrastructuur, de logistieke faciliteiten, en de capaciteit van voorbewerkingsfabrieken de beschikbaarheid van houtachtige biomassa voor de mobilisatie voor export. Indien deze uitdagingen zouden worden overwonnen, dan zouden de kosten en broeikasgasemissies gereduceerd kunnen worden, en zou toegang tot biomassa in afgelegen gebieden mogelijk worden. Dit zou kunnen leiden tot hogere exportpotentiëlen met competitieve kosten en lagere broeikasgasemissies. De haalbaarheid om duurzame biomassa naar de EU te importeren werd met name beperkt door de kosten en de eisen met betrekking tot de te behalen broeikasgasemissiereductie in de REDII vanaf 2026. Als deze grenswaarde verhoogd wordt tot 80%, dan voldoen enkel de duurzame exportpotentiëlen uit de VS, de Ukraine en Colombia, en delen van de potentiëlen van Kenia en Brazilië aan deze strenge duurzaamheidseisen. Ondanks deze beperkingen kan geconcludeerd worden dat substantiële duurzame exportpotentiëlen bestaan. Een van de grootste beperkingen is de mobilisatie van deze potentiëlen. De geschatte export potentiëlen bevatten echter een grote mate van onzekerheid. Deze onzekerheid wordt veroorzaakt door de verhouding residuen-producten, de duurzame oogstfactor en lokale vraag naar biomassa.

c. Wat zijn effectieve duurzaamheidscriteria voor bio-energie, rekening houdend met verschillende type eindgebruik, verschillende regio's en bredere bezwaren met betrekking tot duurzaamheid?

Op basis van een vergelijking van de duurzaamheidscriteria in de RED II, bestaande vrijwillige certificeringsystemen, nationale wetgeving, wetenschappelijke literatuur en het raadplegen van stakeholder, zijn een aantal effectieve duurzaamheidscriteria geïdentificeerd. In deze effectieve duurzaamheidscriteria wordt onderscheid gemaakt tussen verschillende soorten biomassa: afval en residuen, biomassa uit landbouw, en biomassa uit bos. Rapportage van efficiënt gebruik van biomassa is overwogen, maar werd niet effectief bevonden door het ontbreken van een consistente definitie en methode voor effectieve implementatie.

De criteria voor afval en residuen in de RED II bevatten reductie van broeikasgassenemissie en vereisen monitoring of management plannen die bodemkwaliteit en impacts op bodemkoolstof adressen indien afkomstig van landbouwgrond. Om effectief te zijn, is voorgesteld om voor afval en residuen additioneel criteria ter bescherming van water en lucht toe te voegen, evenals arbeidsrechten.

De criteria voor biomassa uit landbouw zouden (naast de criteria voor afval en residuen) ook de bescherming van biodiversiteit, het voorkomen van hoge iLUC risico's, landrechten en voedselveiligheid moeten bevatten. De voorgestelde criteria voor de bescherming van biodiversiteit (zie hoofdstuk 5) zijn strikter dan gedefinieerd in de RED II, terwijl landrechten en voedselveiligheid niet in de RED II zijn opgenomen.

De criteria en vereisten zijn meer uitputtend voor biomassa uit bos. Aanvullend aan de hierboven genoemde criteria voor biomassa uit afval, residuen en landbouw bevatten zijn principes voor duurzame bosbouw, een LULUCF-rapportage en een risico-gebaseerde werkwijze. De duurzame bosbouw principes zijn strenger, terwijl de LULUCF-rapportage vergelijkbaar is met de definitie in de RED II. De risico-gebaseerde werkwijze was aanbevolen in de RED II, en zou toegepast moeten worden om alle vormen beschikbaar bewijs te beoordelen om overeenstemming met alle principes van duurzame bosbouw en koolstof voorraden te beoordelen indien geen certificering mogelijk is in het brongebied.

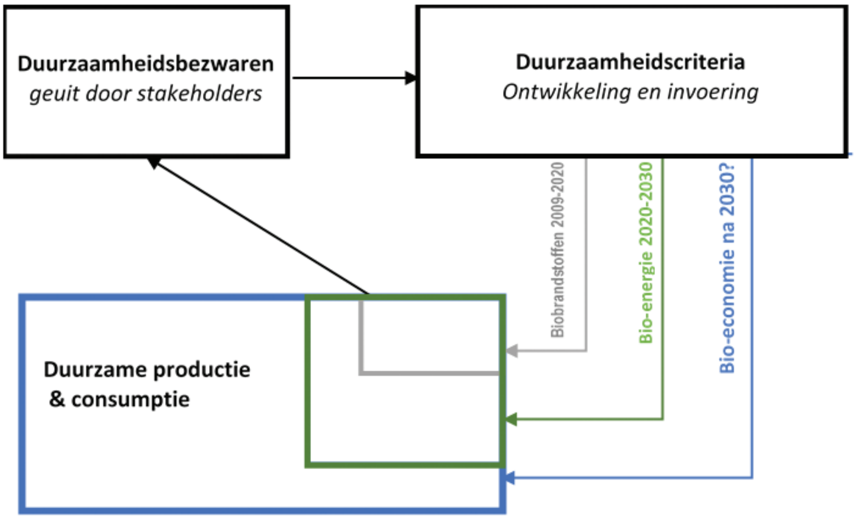
Deze duurzaamheidscriteria worden adequaat geacht om de RED II aan te vullen om zo beter tegemoet te komen aan de duurzaamheidsbezwaren van stakeholders en de duurzaamheid van bio-energie te waarborgen. Het is de verwachting dat deze voorgestelde criteria effectief zijn en op grote schaal zouden kunnen worden ingevoerd. Ze zijn immers al gebruikt en geverifieerd in de praktijk door een of meerdere vrijwillige certificeringssystemen. Gebruik van veel gebruikte vrijwillige systemen is een vooruitstrevende manier om het voldoen aan de effectieve criteria aan te tonen. Deze criteria gelden voor verschillende eindgebruiken die allen dezelfde biomassastromen gebruiken. Vrijwillige systemen zijn flexibel en kunnen aangepast worden om verschillende impacts aan te tonen; daarmee zijn ze sterk in hun werkwijze om duurzaamheid aan te tonen. Echter, hoe veranderingen kunnen worden doorgevoerd en hoe efficiënt vrijwillige systemen zijn moet nog bepaald worden door discussie en overeenkomsten tussen de betrokken stakeholders. Harmonisatie van duurzaamheidscriteria zoals vastgelegd in verschillende nationale wetten en vrijwillige systemen is ook een belangrijke benadering om effectieve duurzaamheidscriteria in de praktijk te implementeren. Verder bevatten "effectieve" criteria ook de elementen lage kosten en lage administratieve lasten vooruitvoerende partijen. Het verenigen van deze elementen met nog meer criteria zal een uitdaging blijven. Een geharmoniseerd duurzaamheidscertificeringssysteem dat rekening houdt met de verschillende bezwaren omtrent duurzaamheid en de duurzame bioenergie waarborgt geproduceerd uit verschillende biomassastromen zou idealiter geïmplementeerd worden op EU niveau.

7.3 REFLECTIE EN AANBEVELINGEN

7.3.1 Reflectie en uitkijk op ontwikkelingen van duurzaamheidskaders voor bio-energie en de bio-economie

Dit proefschrift heeft de voorwaarden verkend voor de bio-energie sector om paden in te slaan naar duurzame vooruitgang. Kijkend naar de ontwikkeling van het duurzaamheidskader voor toenemend gebruik van bio-energie, dan zijn er drie elementen die in een kring met elkaar verbonden zijn, en die belangrijke rollen hebben bij het vormgeven van deze duurzame paden (zie figuur 7.1). Deze elementen zijn (1) de voornaamste duurzaamheidsbezwaren met betrekking tot bio-energie zoals waargenomen door verschillende stakeholders, (2) (effectieve) duurzaamheidscriteria die ontwikkeld en ingevoerd worden om deze bezwaren weg te nemen, en tegelijkertijd te voorkomen dat dit een extra last is voor het gebruik van bio-energie, en (3) de (resulterende) productie en consumptie van bio-energie.

Reflecterend op de invoering van bindende duurzaamheidscriteria zoals gedefinieerd inde RED I in de periode 2009-2020 was de impact van deze cyclus en deze drie elementen beperkt. Gezien de implementatie van de RED II zal de impact van de volgende cyclus groter zijn.



Figuur 7.1. Ontwikkelingscyclus en sleutel-elementen van duurzaamheidskaders voor bio-economy paden

Verder kijkend dan de ontwikkeling van bio-energie, zien we er al strategieën voor de ontwikkeling van de bio-economie vastgesteld zijn in nationaal en regionaal beleid.[314,315] Indien we de mondiale ontwikkelingen tot 2050 schetsen, dan is de verwachting dat verschillende internationale en regionale initiatieven ontplooid zullen worden die om duurzame paden voor de verschillende sectoren vragen. Dit zijn onder andere het klimaatverdrag van Parijs,[140] de EU strategie voor de ontwikkeling naar een low carbon economie en een duurzame bio-economie,[271] en meest recent de EU Green Deal – een roadmap om de Europese economie te verduurzamen.[322] De voorwaarden om in richting van duurzame paden te bewegen en de drie elementen die in dit proefschrift onderzocht worden zijn niet alleen maar relevant voor bio-energie maar ook voor de bio-economie in de toekomstige roadmaps. Het is goed mogelijk dat de drie elementen geïdentificeerd in figuur 7.1 op de langere termijn steeds belangrijker zullen worden, zowel wat betreft verschillend eindverbruik als ook de geografische dekking.

7.3.2. Aanbevelingen

- Aanbevelingen voor bezwaren van duurzaamheid biomassa
Stakeholderonderzoek in dit proefschrift heeft laten zien dat er op de lange termijn gestreefd moet worden naar een holistische aanpak van duurzaamheid. Beleidsmakers zouden daarom kunnen overwegen om duurzaamheidscriteria vast te stellen voor alle sectoren van de bio-economie, of om naast bio-energie, ook ondersteunende maatregelen te nemen voor sectoren die dezelfde soorten biomassa gebruiken voor de productie van bio-based materialen. Ook wordt aanbevolen om oplossingen te vinden voor de mobilisatie van duurzame biomassa, geavanceerde verwerkingstechnologieën, een hogere keten-efficiëntie, en een betere samenwerking en kennisuitwisseling tussen verschillende sectoren van de bio-economie.

- Aanbevelingen voor de ontwikkeling en implementatie van duurzaamheidscriteria
In dit proefschrift is onderzoek gedaan naar (effectieve) duurzaamheidscriteria voorde bio-energie sector. Deze criteria zijn ook relevant en toepasbaar voor andere sectoren van de bio-economie die dezelfde soorten biomassa gebruiken, maar niet noodzakelijk compleet. Mogelijk zijn er additionele duurzaamheidscriteria noodzakelijk die risico's van ongewenste milieueffecten van deze sectoren adresseren.

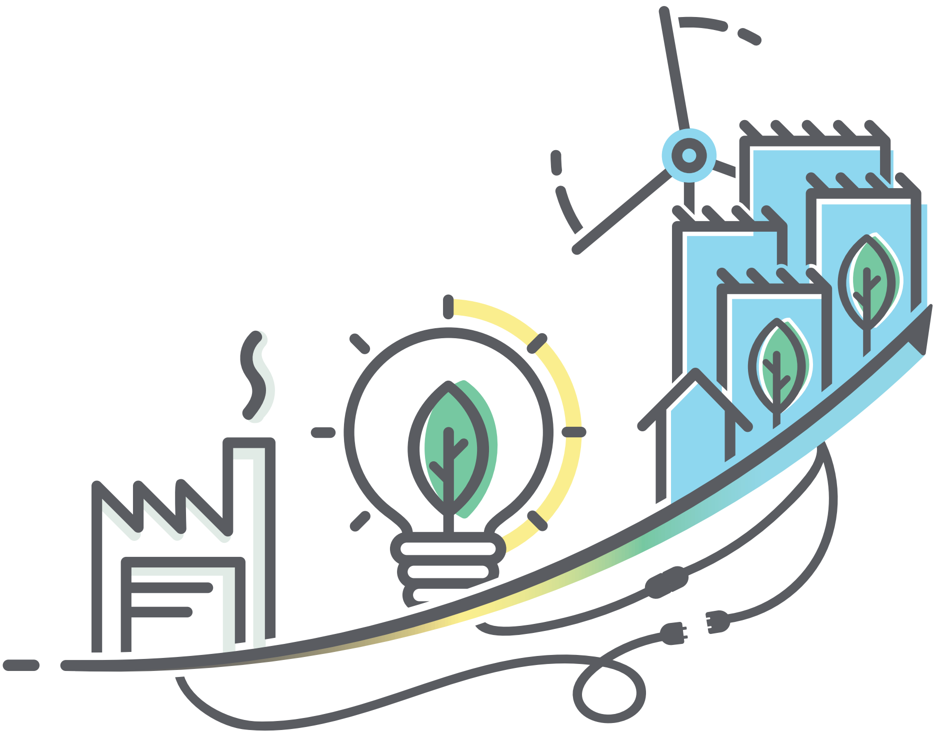
Bij de implementatie van duurzaamheidscriteria in nationaal beleid en certificeringssystemen, moet ook goed gekeken worden naar het compromis tussen de kwaliteit en kwantiteit van biomassa. Wanneer duurzaamheidscriteria breed worden toegepast op de gehele bio-economie, dan is het van belang dat een optimale balans wordt gevonden tussen de kwaliteit, betreffende de minimale broeikasgasemissie reductie (en andere milieueffecten), en de hoeveelheid biomassa die onder deze criteria beschikbaar is voor sectoren van de bio-economie. Ook is de erkenning van vrijwillige duurzaamheidscertificeringssystemen door nationale autoriteiten van belang. Dit kan zorgen voor een verbeterde legitimiteit van deze systemen, een hogere efficiëntie in het certificeringsproces en een bredere implementatie van duurzaamheidscriteria. Waarborging van duurzaamheid van alle sectoren van de bio-economie vraagt ook om meer uitgebreide richtlijnen voor implementatie van criteria en transparantie over duurzaamheidsprestaties.

Een van de openstaande vragen blijft de toewijzing van milieueffecten bij meerdere functies van productieprocessen. Bij bioraffinage worden meerdere producten uit biomassa gewonnen. Dit kunnen naast energieproducten zoals biobrandstoffen, warmte en elektriciteit ook andere producten zijn zoals bio-based materialen. Het wordt aanbevolen om dit vraagstuk van multifunctionaliteit en allocatie van bioraffinage op EU niveau aan te pakken. Duurzaamheidscriteria worden op de lange termijn mogelijk toegepast op alle sectoren van de bio-economie. Meer onderzoek is daarom nodig naar een geharmoniseerd en holistisch duurzaamheidskader en een effectieve implementatie van dit raamwerk voor de gehele bio-economie, inclusief energie en materialen.

- Aanbevelingen voor de duurzame biomassaproductie en -consumptie

Voor het berekenen van het potentieel van geïmporteerde duurzaam geproduceerde biomassa werd een methode ontwikkeld in dit proefschrift waarin duurzaamheidscriteria werden meegenomen. Deze duurzaamheidscriteria waren hoofdzakelijk gebaseerd op de RED I met een aantal aanvullende sociale en economische criteria relevant voor de lokale context van het productiegebied. Om alle ongewenste effecten uit te sluiten, zijn mogelijk additionele en strengere duurzaamheidscriteria noodzakelijk. Een uitgebreide, lange termijn analyse van het duurzame aanbod en de mogelijke effecten van de productie en mobilisatie van biomassa voor de bio-economie is van belang voor stakeholders van de bio-economie, waaronder investeerders maar ook beleidsmakers in het opstellen van relevante beleid.

Voor in de berekening van de beschikbaarheid van houtachtige biomassa voor export werd, door tijdsbeperkingen, een tijdshorizon tot 2030 gehanteerd en werd het aantal productieregio's buiten de EU beperkt tot zes landen. Het wordt aanbevolen om in nader onderzoek ook naar andere mogelijke productieregio's te kijken voor mogelijkheden van duurzame biomassahandel. Ook wordt het aanbevolen om de tijdshorizon tot tenminste 2050 (en na 2050) te vergroten gezien het belang van duurzame biomassa in de lange termijndoelen voor mitigatie van klimaatverandering.



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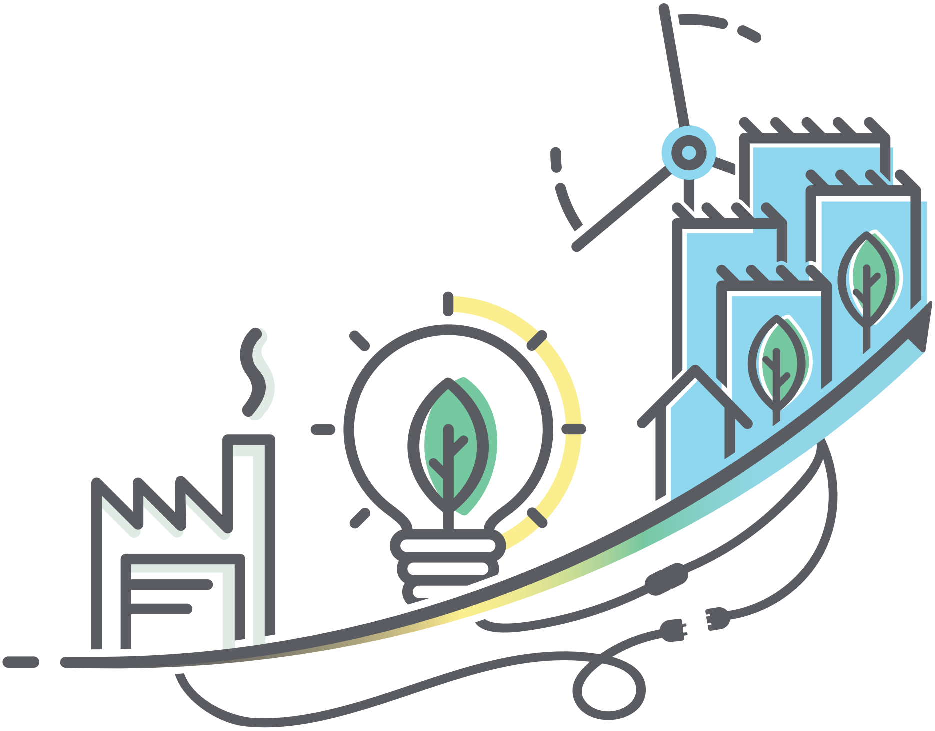

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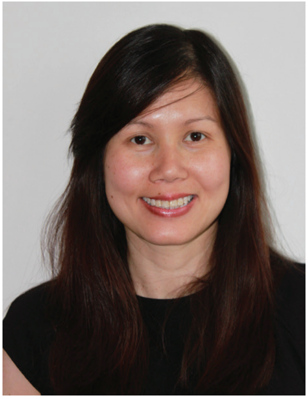

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After receiving her Master degrees, Thuy worked as a programmes officer, then a consultant in environmental standards and management, climate and energy resilience. Thuy joined the Copernicus Institute of Sustainable Development, Utrecht University in early 2014. Thuy have been involved in finding sustainable solutions for bioenergy and resources, identifying issues of sustainable trade, quantifying sustainable biomass potentials, efficient supply chain management, sustainability criteria and certification schemes for bioenergy.

After completing her PhD, Thuy plans to grow her career further in finding sustainable solutions for the bioeconomy sectors. Parallelly, she also focuses a new career path on sustainable business for the circular economy sectors.

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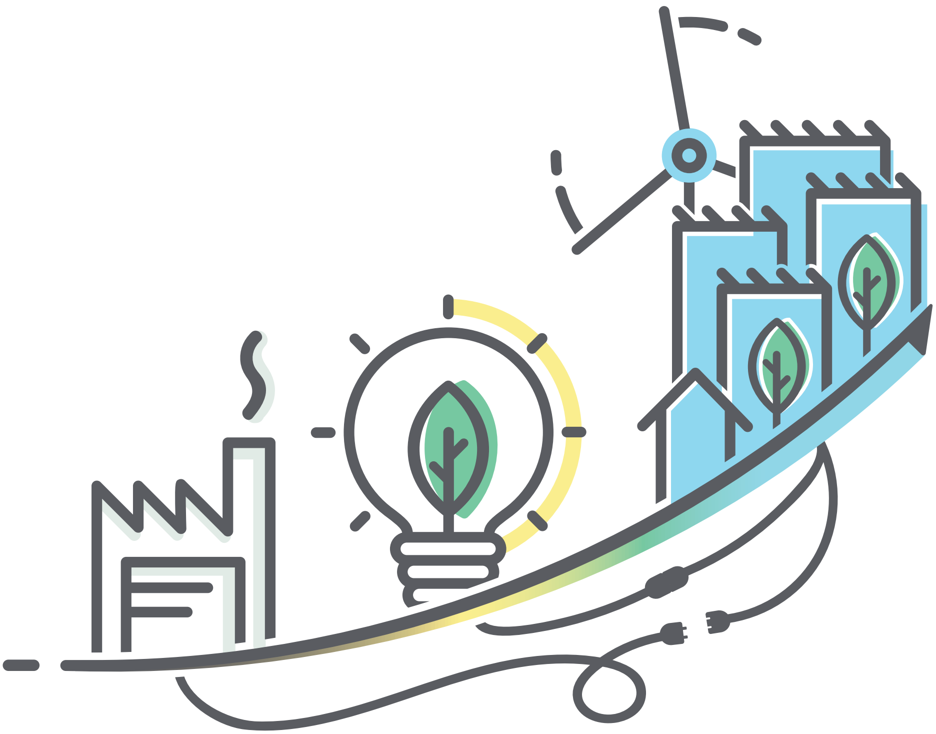

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