ETIP Bioenergy

European Technology and Innovation Platform

OPPORTUNITIES AND CHALLENGES FOR BROADENING BIOMASS FEEDSTOCK IN EUROPE

INDEX

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INTRODUCTION

Resource efficient biomass feedstock supply is essential to sustain current capacities and facilitate market development for advanced bioenergy and biofuel technological pathways.

The aim of the working paper is to: synthesize recent research targeting European biomass feedstock for bioenergy; identify opportunities and challenges and provide research and policy relevant recommendations for 2030 and beyond.

Four research areas are analysed: improving practices for forest biomass supply and logistics; biofuels from marginal land; biomass supply and cost supply assessments and certification & standardization.

1 IMPROVING PRACTICES FOR FOREST BIOMASS SUPPLY AND LOGISTICS

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Biomass from forestry originates from various sources and can be processed into many different forms. In this chapter we follow the classification of sources presented by Anttila et al.[1]:

- **LOGGING RESIDUES OR SLASH** Crown biomass (branches and leaves or needles) and stemwood loss (non-merchantable timber, under-sized tops and small-sized stems). Logging residues are typically harvested from final fellings. Types of logging residues can vary from branches to timber-size stems or stem parts.
- **SMALL-DIAMETER TREES** Small-sized trees from pre-commercial thinnings. These include trees too small for material wood product use removed in a thinning operation to improve the remaining forest stock or as a fire control practice. This type of direct energy wood may include some trees fulfilling the size and quality demands for material wood product use, when a separate harvest for other segments of the wood products industry are not economically feasible. Small trees can be harvested as whole trees or delimbed. In an integrated harvest energy wood and industrial roundwood are co-harvested from the same stand.
- **STEMWOOD** Stemwood not suitable for other non-energy industrial processes due to undesirable characteristics (e.g. dimension, species, mechanical defect). Stemwood meeting requirements for feasible use by the material wood products industry might be included in this category if no local demand exists.
- **STUMPS** Wood from stumps and roots from final fellings.

To some extent supply chains and technology can be considered mature and the differences of supply chains between regions originating from the differences in operating environments (**Figure 1**). Despite the differences, some common features between the supply chains can be identified. When so-called cut-to-length method (i.e. stems are cross-cut to desired dimensions already in forest) is used in timber harvesting biomass is first scattered on a forest site – either as ready for off-road transport after extraction of the main product (in the case of logging residues), needs to be cut (small-diameter trees, stemwood) or extracted (stumps) first[2]. The off-road transport phase moves the biomass to the road-side where it is typically stored to wait for chipping or crushing or on-road transport. For longer distances road transport can be followed by rail or waterway transport. Generally, supply chains can be characterized by the location of chipping or crushing phase (stand, road-side, terminal or plant)[3].

During the past decade a vast body of research and development in the field of energy-wood supply and logistics has improved the efficiency and sustainability of supply[5,6]. There already are many regions where the mobilization degree of forest biomass for energy is high, and organizational learning has taken place over decades. Thus, virtual learning assisted technology transfer and adopting of best and proven practices could improve the uptake of new technology and methods elsewhere in Europe.

Piles of logging residues on a harvesting site in Finland. Source: ErrKi Oksanen

Key characteristics of forest supply chains

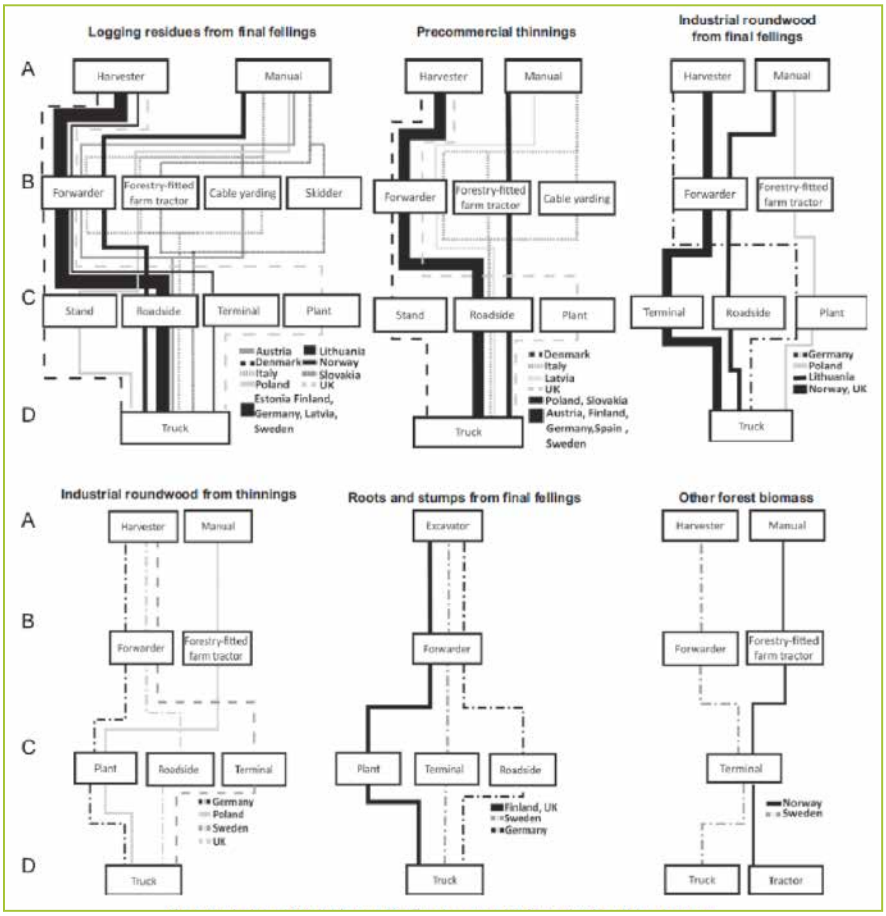

Figure 1. Supply chains of energy wood differ between countries (Díaz-Yáñez et al. 2013)[4].

BIOMASS YIELD

It is possible to increase biomass yields by intensifying forest management. E.g. Hynynen et al.[9] estimated that the annual removals in Finland could be increased up to 40% compared with current level in a sustainable manner without endangering future wood production possibilities. Alternatively, current level of roundwood cutting removals can be maintained in the future using a significantly smaller forest area for commercial wood production. Potential means to increase biomass yields include fertilization, improved regeneration material, ditch network maintenance, successful regeneration (e.g., tree species and spacing) and suitable pre-commercial stand density and rotation length. Finding the locally right combination of these means would not only increase the production of timber and energy biomass, but also increase carbon sequestration (and stocks) in the forest ecosystem and decrease the CO^2 emissions caused by the use of energy wood[10].

HARVESTING

Already with the present yield levels availability of biomass could be increased by developing technologies to access difficult terrains. Harvesting on steep slopes and soft soils is costly and the climate change will further weaken the situation. Furthermore, there is pronounced seasonal variation in harvesting levels in regions where the weather conditions prevent round-the-year harvesting due to low bearing capacity.

Digitalization, big data and sensor technology have been proposed as means to lower the costs and to decrease environmental burden of harvesting. Erber and Kühmaier[11] anticipated that the future trend will be towards semi-automated and remotely-controlled fuelwood harvesting. Static or dynamic trafficability maps are based on digital elevation models, soil type data, remote-sensing-based estimates of growing stock and weather data and can be useful in selecting right targets for biomass supply[12]. Decision support systems can be used for the identification of suitable biomass harvesting objects and also those to be left outside sourcing due to e.g. high harvesting costs or environmental concerns. In addition, by using these data also main extraction roads can be proposed for a harvester[13]. However, further research is needed to develop the optimization of the strip roads and forwarding.

CHIPPING AND TRANSPORT

Seasonal variation can pose a problem for biomass transportation, too. Intelligent transport planning is needed, if part of the road network is unavailable due to spring thaw or rainy season. Information-based selection of storages as well as feed-in terminals can be used to level the variation[14,15]. Versatility of transportation equipment represents one way of achieving year-round employment and ensuring the availability and stability of a professional workforce. The versatile load space enabling, e.g. backhauling, is also a clear benefit with long transporting distances, because larger procurement areas, increasing prices of transporting fuel and higher amount of time consumed by

OPPORTUNITIES

- There still exists a large untapped potential of biomass from forestry. According to Lindner et al.[7] the biggest potentials can be found in Germany, Sweden, France, and Finland. In addition, especially in Southern and Western Europe forest utilization rates are low and in half of the EU countries less than two thirds of annual increment has been harvested[8].
- The potential could be further extended by developing technologies to access difficult terrains. Such terrains include steep slopes (especially in Central and Southern Europe) and peatlands (especially in Northern Europe).
- Digitalization and big data provide opportunities to radical innovations in biomass supply and logistics.

CHALLENGES

- Climate change poses challenges to the whole European forestry.

  In Southern Europe droughts will be more common reducing growth and increasing risk for fires.

  In Northern Europe, on one hand, the increased temperatures will increase growth, but on the other the risk of natural damages will increase and the conditions for logging and transport deteriorate.

transportation will increase the costs of the forest chips and forest industry by-products[16].

Standing times for the chipper and truck-trailers due to truck-chipper interactions must be considered and quantified when seeking optimal set-ups for the forest chip supply chains for different transporting distances[13]. The capacity balance between truck-trailers and chippers determines the outcome of the system. Therefore, the number of truck-trailers must be adjusted to the transport distance and the productivity of the chipper. The factors influencing transporting efficiency and cost are payload, loading and unloading time, transporting distance, hourly costs and operational delays such as waiting and auxiliary times.

The results indicate that the new dimension standards and weight limits and modern ETS-technology (Electronic Trailer Steering System) for heavy vehicles represent a significant cost reduction and efficiency improvement potential when transporting forest chips and forest industry by-products[13]. Utilizing modern vehicle designs such as a liftable axle group or steering axles at the rear end of a trailer of this size vehicle increase manoeuvrability on forest roads. The chipping time consumption is inversely proportional to engine power[17].

With the right hybrid system design a small diesel engine combined with a hybrid system could perform as good as a larger displacement diesel without hybrid, as long as it is capable of meeting the same short-term power demands. On the other hand, a hybrid system could be used to provide power boost functionality to a present solution and make a higher productivity and performance without the need to increase the engine displacement and dimensions.

QUALITY MANAGEMENT

The quality management of biomass along the supply chain has been found to be extremely important[18]. Good management of stockpiles, improvement of fuel quality by drying and screening impurities from the energy biomass enhance the performance of the entire system[19,20]. By using weather data-based prediction models, the moisture content of biomass can be estimated at any given time and optimal delivery times can be planned[21,22]. In addition to moisture content, ash content is one of the major factors decreasing the calorific value of the fuel wood, and high levels of mineral contaminants can also affect ash melting behavior during combustion, leading to sintering and drift problems[16].

Biomass can be stored either as comminuted (chips or firewood) or uncomminuted (whole trees, stem wood and logging residues). Dry matter losses are an increasingly discussed topic and are seen to be crucial for the financial viability of the forest biomass supply[23,24,25,26]. Woody biomass with high moisture content is more susceptible to colonization by fungi and mold and at a faster rate[27,17]. These microorganisms, via metabolic activity, generate heat, which in turn accelerates oxidation, moisture adsorption and other chemical processes resulting in dry matter loss. Thus, proper storage strategies play a significant role in succeeding with a cost-efficient forest energy supply. On the other hand, it has been shown that in long-term storing outdoors, there will evidently be some dry matter and energy losses due to microbial activity[17]. The economic losses caused by dry matter losses could be 4–17% of the energy wood procurement costs, depending on the storage time, raw material and dry matter loss rate[18]. Under these circumstances, green delivery and active drying might be viable alternatives. Furthermore, fresh feedstock may even be desirable for the new biorefineries.

Guidelines for forest biomass supply

(adopted from Anttila et al.[1])

Extant guidelines for harvesting energy wood generally aim to avoid or mitigate potential detrimental effects of its removal. They offer specific instructions on harvesting outcomes and on particular methods based on research and practical observations.

Typically constraints restricting both selection of suitable sites and harvest level at a single harvest stand are given. These constraints relate to soil productivity, soil and water production, biodiversity protection, soil bearing capacity and recovery rate. Notably, guidelines are not mandatory, but following them may be a pre-requisite for certification by third-party environmental programs. Thus, the guidelines are commonly followed in commercial-scale operations. Guidelines have been developed for a few specific forest types and even site levels based on the dominant forest type and soil conditions[28,29,30,31,32,33].

In Finland, guidelines for sustainable forest management are widely implemented[34]. In addition, specific guidelines have been developed for the harvesting of energy wood[35]. These guidelines were drafted following a participatory process with different stakeholder groups inclusive of government authorities, entrepreneurs, forest owners, industry, non-government agencies, and researchers.

The guidelines provide forest managers alternatives for energy wood harvesting to select the ones better matching particular management objectives. Energy wood guidelines start by describing the framework and general instructions for protecting nature. These are followed by detailed instructions for harvesting wood energy from timber harvests as well as for storage, quality control and work safety. Quantitative constraints restricting harvesting levels are given.

For example, whole tree harvesting is not recommended on mineral soils classified as sub-xeric (or weaker), on peatlands with corresponding low nutrient levels, and on mineral soils where the share of Norway spruce (Picea abies) is over 75%. On sites suitable for whole tree harvesting it is recommended that 30% of original crown biomass is left on site.

Delivery of woodchips from forest biomass at a district heating plant in South Tyrol, Italy. Source: ETA Florence

1 R&I RECOMMENDATIONS

METHODS AND DATA

- Use enabling technologies (digitalization, big data, sensor technology) for resource management (including big data and automation for optimal harvesting, storage, etc.)
-

TECHNOLOGY DEVELOPMENT

- Increase biomass yields and availability to meet the growing demand of multiple sectors.
- Develop appropriate logistics to ensure year-round supply for the biorefineries; including research on transportation and storage issues (short and mid-term)
- Integrate biomass value chains with other value chains (e.g. integrated harvesting of residues & the main product(s), new alternatives for backhauling, multiple-use machines to alleviate seasonal fluctuations)
- Developing technologies to access difficult terrains. Such terrains include steep slopes, peatlands, etc. (short and mid-term)

ENVIRONMENT AND ECOLOGY

- Research on optimisation of harvesting and transport within sensitive environmental ecosystems, e.g. dry arid south Europe with increased risk of fires; areas with flooding problems, etc. (short and mid-term)

2 BIOMASS FROM MARGINAL LAND

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What is marginal land?

Economic definition: that is an area where a cost-effective production is not possible, under given site conditions, cultivation techniques, agricultural policies as well as macro-economic and legal conditions" (Schroers, 2006)[36]; where revenue is just equal to costs of production (Peterson and Galbraith 1932)[37].

Physical and production definition: marginality is based on soil suitability and restrictions are often adopted by soil scientists and agronomists for the purpose of land use planning. It refers to land of poor quality for agriculture or susceptible to erosion or other degradation (Lal 2004)[38].

OPPORTUNITIES

- Significant and unused natural asset: Use of marginal land has gained significant attention due to climate change and the projected scarcity of natural resources in the future: large areas affected already worldwide, land degradation and 'land grabbing' is a global issue. (short term with long-term effect)
- Avoidance/minimization of conflicts in the 'food vs. fuel' debate: growing energy crops in marginal land facilitates reduced competition as compared to agricultural land use for food production purposes. (short term with long-term effect)
- Increase of biodiversity: creation of a diverse landscape structure elements ('niche function' | habitat function). (mid-term and long-term)
- Creation of new jobs for, e.g. farmers, foresters, engineers and scientists specialized in the use of marginal land for bioenergy purposes. (short and mid-term)
- GHG mitigation and carbon sequestration by growing perennial plants on degraded land à enrichment of soil organic carbon in the top- and subsoil. (long-term)

CHALLENGES

- The main challenges for biofuels from marginal land concern on one hand the terminology and definitions of the various land categories as well as the potential of these land types to produce biofuels in a sustainable and cost-efficient manner.

Cultivation of miscanthus and willow on a formery illegal dump site in the Vinnytsia region (Ukraine). Source: SEEMLA project

Terminology and definitions

There is great uncertainty regarding common understanding of 'marginal land' and no uniform definition can be found in literature. Many approaches consider either biophysical or socio-economic criteria, but most cases do not consider multi-criteria approaches. In the literature there is no unified definition of marginal land. Many approaches consider either biophysical or socio-economic criteria, but in many cases do not consider a multifactorial approach.

Often the term 'marginal' is mentioned addressing economic and agronomy issues. Tilman et al. (2006)[39] apply the term 'marginal' to describe land of lesser physical quality for agriculture with respect to yield, while Kort et al. (1998)[40] refer to economically marginal land. In this context, Shortall (2013) defines marginal land rather cumulative, including idle, unused, spare, abandoned, under-used, set aside, degraded, fallow, or underutilised land. In 2012, Dauber et al.[42] published a paper referring to surplus land including the category 'marginal land' -, focusing on bioenergy production, in detail also on advanced (bio)fuels, and environmental and socio-economic implications. **Figure 2** presents different types of surplus land and their interrelation.

In addition, the following paragraphs provide insights to the definitions of these land types according to recent literature.

SURPLUS LAND Based on Rounsevell et al. (2006)[43], Faaij (2007)[44], Lovett et al. (2009)[45], and Jingura et al. (2011)[46], Dauber et al. (2012) two different types of 'surplus land' can be identified:

- land that is currently not used for food and fibre production because of poor soil fertility, and
- land that set aside due to an increase in yield of food/fibre production, resulted from intensification and thus a decreased requirement for land.

According to the World Bank (2010)[47] definition, both marginal and surplus land become collective terms which include several land categories. In this context, the World Bank concluded that the overall area of the remaining set aside arable, or 'surplus land' that is uncultivated, not forested, and with population densities less than 25 persons per square kilometer, covers roughly 445 million ha. Dauber et al. (2012) consider these types of land as potentially suitable for bioenergy crops cultivation.

IDLE LAND According to OEKO (2006)[48], Dauber et al. (2012) state that this term includes all types of unused land, such as abandoned farmland, degraded land, waste land, and areas of undisturbed wildlife. The term of idle is synonymously used with the terms of unused land and mainly reflects its economic potential.

ABANDONED LAND The definition of this term is presented in the work e.g. of Kort et al. (1998) and has been previously used for agricultural land or pasture, which was abandoned by farmers for economic or political reasons. According to Wiegmann et al. (2008)[49], abandonment can occur anywhere on both fertile and less fertile soils, which is usually caused by increasing labor and land costs, lower product prices, or the application of new, more efficient techniques. Three categories of abandoned land can be defined:

- land abandoned because of increases in agricultural productivity,
- land abandoned because of its inferior agricultural performance, and
- land abandoned for economic reasons such as higher income levels in industrial jobs, increasing rents or reduced subsidies.

Wiegmann et al. (2008), and Dauber et al. (2012), consider land that has been abandoned due to inferior fertility as suitable for energy crop growing. This category of land has a cost-efficient level of agricultural productivity, allowing biomass production without preceding restoration.

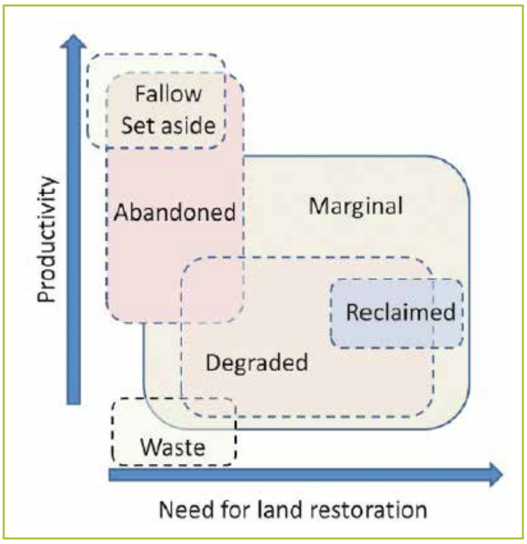

Figure 2 Scheme of the interrelation of different classes of surplus land, in this case focused on marginal land (Dauber et al. 2012) and their relationship to the productivity and the needs for land restoration.

DEGRADED LAND Investigation of Plieninger and Gaertner (2011)[50] show that in the current literature the term 'degraded' is widely used and applied for different land covers, including abandoned farmland, postmining areas, and badlands. For the recognition and categorizing degraded land is widely used data from FAO and UNEP (e.g. GLASOD degradation data, Land Degradation Assessment in Drylands – LADA, FAO TERRASTAT).

According to Wiegmann et al. (2008), the process of land degradation can be naturally induced or caused by intensive anthropogenic activity such as overexploitation or improper use of land, both in a long-term result in loss of ecosystem function and land productivity. In UNEP (2007) land degradation is defined as loss of ecosystem function and services, because of natural or artificial disturbances from which the system cannot recover unaided. Bergsma et al. (1996) draw more attention to the improper use of the land that to their mind is a major cause of land degradation today.

Wiegmann et al. (2008) refer term 'degraded' to land productivity potential and identify several slightly different definitions on this land, which concerns reasons inducing degradation processes or characterizes state of ecological system:

1. land degraded because of human activity or both human and naturally induced,
2. system required aided or unaided recovery,
3. condition of time horizon which is observed over time and status of land is considered.

Plieninger and Gaertner (2011) suggested a conceptual difference between degraded and abandoned land. They consider that the term of degraded land should be used in respect of severe and substantial loss of productivity and soil fertility. Dauber et al. (2012) emphasize that both anthropogenic and naturally degraded lands become valuable components of biodiversity.

The EU included the concept of degraded land in the Renewable Energy Directive 2009/28/EC (2009), and supports the establishment of biomass production on such unfavorable land. According to Dauber et al. (2012), a feasibility to use degraded land for bioenergy crops production depends on the severity of degradation and productivity of the time horizon which is under major degradation influence.

Sewage irrigation fields. Source: FORBIO project

RECLAIMED LAND This term is widely used in the context of anthropogenic modified land (e.g. due to drainage), post-mining areas and land previously used for industrial purposes (brownfields), and contaminated land improved by remediation (Daily 1995[51], Dauber et al. 2012). According to Dauber et al. (2012), reclaimed lands have solid underground of their further use for biomass cultivation, but their potential depends on the severity of anthropogenic impact and undertaken efforts referring to land rehabilitation/reclamation.

CONTAMINATED LAND Daily (1995) defined this type of land as a separate category in an ecologic context, referring to an increased level of pollution by hazardous waste. This land has the potential to be reused once it is remediated. Depend on the level of land contamination and investments spent to reclamation procedure; it must be decided case wisely, if such land can be considered as suitable for bioenergy crop production, based on national legislation.

WASTE LAND This is a term related to land productivity potential. Oldeman et al. (1990)[52] identified wasteland and land of low natural productivity potential, which is unfavorable for agriculture. Wiegmann et al. (2008) include the wastelands area without agricultural potential such as active dunes, salt flats, rocky outcrops, deserts, ice caps and arid mountain regions. These lands cannot be cultivated under any conditions because of boundaries set by climate and soil. For this reason, waste lands are not suitable to produce neither agricultural nor bioenergy crops. According to Dauber et al. (2012), without improvements and external inputs, it will be impossible to receive crops yield on waste lands as the agricultural activity will be always limited by plants physiological needs.

Dale et al. (2010)[53] suggested that crop breeding and biotechnology, including genetic engineering, will be able to allow expanding boundaries for growing bioenergy feedstock.

FALLOW LAND According to Krasuska et al. (2010)[54], (cf. Dauber et al., 2012), this land category should not be considered as 'marginal'. Fallow land is a part of a crop rotation system with a high-level productivity, but suspension of its cultivation for at least one vegetation period was caused to achieve a recovery of soil fertility. The temporary suspension of cultivation does not deal with a limit of soil productivity potential; it is based on the artificial decision to improve ecology and fertility standards of this land.

SET ASIDE (cf. abandoned land) According to Alexopoulou (2012)[55] (cf. Dauber et al., 2012), set aside land is a category of land which agricultural use is limited by a politically motivated decision. Suspension of this land cultivation caused either by agro-environment scheme or by a mechanism to reduce food production. Such land keeps high fertility potential and is set aside for the agricultural exploration terminated for either rotation period or can follow permanent basis.
Wiegmann et al. (2008) stated that many scientists follow an economic approach of the term marginal land, not including subsistence agriculture. Dale et al. (2010) and Dauber et al. (2012) considered that the term marginal land is primarily used for describing degraded, abandoned, reclaimed or natural wastelands. These are lands with characteristics that make them unsustainable or inappropriate for common agriculture use under given agricultural practice, economic and political climate.

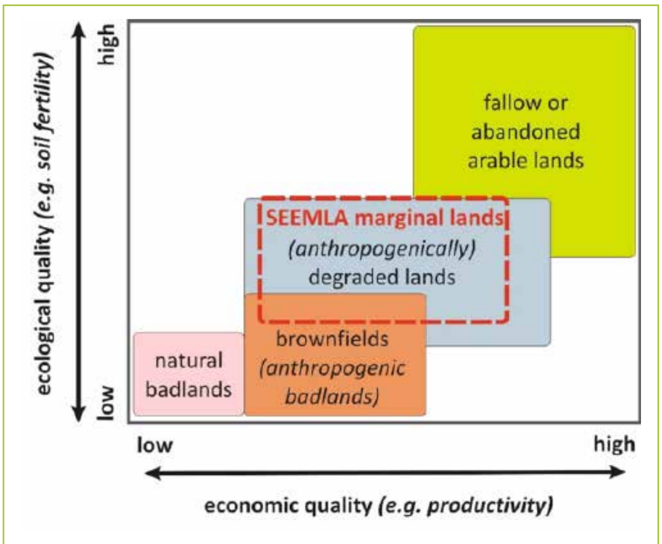

Figure 3 Classification scheme for marginal land in the SEEMLA approach context (developed by BTU)[64] modified after and adapted from Dauber et al. (2012).

This concept has been adapted in the SEEMLA[56] approach (**Figure 3**) and even more specified, focusing on appropriate bioenergy crops suitable for being grown on such marginal land. In the project ADVANCEFUEL[57], marginal land is defined based on Wicke (2011)[58], as land on which cost-effective food and feed production is not possible under given site conditions and cultivation techniques. This definition covers land that is biophysically marginal as well as land that is marginal for economic reasons.

Dauber et al. (2012) emphasized that categorizing or quantifying marginal lands in respect of availability and suitability for bioenergy crops cultivation underlies great uncertainties and requires wide-ranging estimates. According to Perlack et al. (2005)[59], and Gopalakrishnan et al. (2009)[60], recent suggestions on redesigning landscapes to incorporate sustainable bioenergy crop production on marginal land must include categories of idle and fallow cropland, land of Conservation Reserve Programme (CRP) – taking the respective legislation into account -, as well as growing bioenergy crops in buffer strips along roadways, rivers and streams, contributing also to the closure of nutrient cycles. There are further concerns regarding water quality, when annual tillage crops are grown for bioenergy, including eutrophication from nutrient movement (dissolved and with soil), turbidity and excessive sedimentation from soil erosion (NRC 2008)[61]. This may potentially be leading to conflicts with other types of land use or (non-marketable) ecosystem services, if water is scarce (Fritsche et al. 2010)[62].

Hence, energy crops with high demand in water should be grown in regions with high effective

Potential of marginal lands to produce biomass

Kang et al. (2013)[65] analysed marginal lands under different evaluation methods and practices varies from 320 million ha to 1.3 billion ha. Wood et al. (2000)[66] identified area of marginal lands that was about 36 percent of global agricultural land or 1.3 billion ha; Campbell et al. (2008)[67] investigations resulted in 384 to 471 million ha and Cai et al. (2010)[68] stated 320-702 million hectares of marginal lands, if "only abandoned and degraded cropland and mixed crop and vegetation land, which are usually of low quality, are accounted".
Converting marginal land to bioenergy crop production, according to Kang et al. (2013), will allow producing about 1.4 to 2.1 billion tons of biomass globally.

Based on the investigations of Fischer et al. (2009)[69] Europe's agricultural land, covering the EU27, Norway, Switzerland and Ukraine, comprises 164 million hectares of cultivated land and 76 million hectares of permanent pasture. Cultivated areas dominate agricultural land in Eastern Europe, while the bigger part of permanent grassland is in Western Europe. Furthermore, based on projections from Fischer et al. (2009), by 2030 under different economy development scenario of some 44–72 million hectares could be made available in the EU28 and Ukraine without compromising Europe's food and feed sectors and shifted to marginal area.

Investigations of Cai et al. (2011) which were based on physical conditions such as soil productivity, land slope and climate, show that the countries/regions with major agricultural production capacity in the world may have 256 to 463 Mha of land available for that purpose, if only abandoned or degraded cropland is used for biofuel production. Furthermore, calculations showed that on marginal lands, depending on scenarios of their use, it could be possible produce different amounts of fuel and energy,

- if planting prairie grass, it provides about 2-7% of the current world liquid fuel consumption;
- if planting second-generation biofuel feedstock, about 8-34%. But, if converting marginal grassland to marginal land used for bioenergy production (about 1.4 Mha), the demand of liquid biofuel would be covered by 23-48%.

On a global scale, based on an evaluation of different scenarios of land use by IEA (2011)[70], Africa alone may provide from one-third to half of its land to produce biofuel; Africa and Brazil together may cover over half of such requirement.
The productivity of bioenergy crops on marginal lands highly depends on the level and type of land marginality as well as on the selection of the most suitable bioenergy crops (Tilman et al. 2006; Schmer et al. 2008[71], cf. also H2020-funded projects SEEMLA[18], FORBIO[72]).

Considering surplus land as collective marginality term and depending on the objective and/or availability of data and crops considered, e.g. annual or lignocellulosic crops, the global bioenergy potential of surplus land ranges from 250 Mha to ca. 1.6 Mha (IEA 2011) (**Figure 4**).

Investigations by Gopalakrishnan et al. (2011) made in the state of Nebraska (USA), showed that among 12 million ha (30 million acres) environmentally marginal lands, 8.4 million ha (21 million acres) are lands with nitrate-contaminated groundwater, the other 3.2 million ha (8 million acres) irrigated cropland. The authors derived from their findings that the most important and productive bioenergy crops for these areas are second-generation lignocellulosic bioenergy crops such as switchgrass (Panicum virgatum L.), miscanthus, and short-rotation woody crops, e.g. willow, poplar, that are also expected to have limited environmental impacts, functioning e.g. as buffering zone for excessing nutrients.

Rockström et al. (2009)[74] and Dauber et al. (2012) identified that crops used primarily for second-generation biofuels are the most suitable for being cultivated in marginal lands.
According to Cofie and Penning de Vries (2002)[75], or Dornburg et al. (2010)[76], degraded marginal lands are prone to high risk for an efficient biomass production. Degradation requires cost intensive and time consuming (long-term) efforts for land reclamation, and generally deals with a low nutrient efficiency resulting in low yields with high risks of crop loss.

In Europe, recent research from the S2Biom project[77] reported that there are two broad categories of unused land in Europe. Firstly, land which is difficult to access, has poor soil or climate and has always been utilised extensively. Secondly, land that was previously farmed but has been

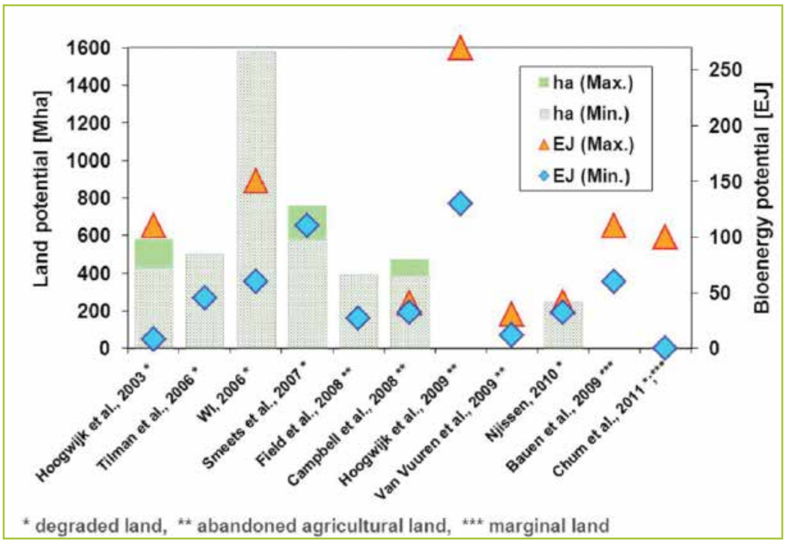

Figure 4 Land and bioenergy potential of different marginal (surplus) land categories (Dauber et al., 2012, based on IEA, 2011).

abandoned because of the increasing decline in economic margins reached by existing practices or because of marginalisation because due to overexploitation, pollution, climate change or declining rural population.

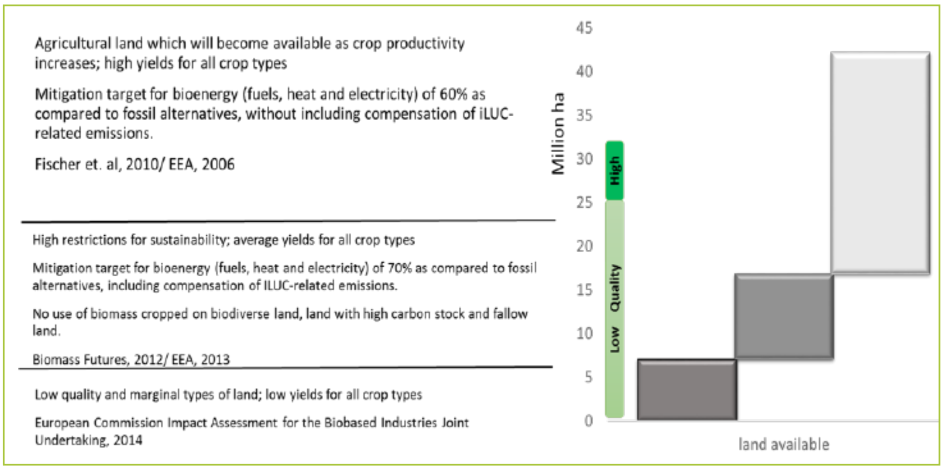

Figure 5 *Land availability (in the green column) for dedicated non-food lignocellulosic crops in Europe (in green the estimates from S2Biom for availability of low (marginal) and high quality land available by 2030).*

The analysis performed in S2Biom for land availability for perennial lignocellulosic crops suggests there is a large land resource in Europe that is currently or will become unused. However, putting this land in biomass production by 2030 will be a significant challenge.

Estimates from previous studies for the EU in 2030 are in the range of 7-40 million ha of biomass while the respective figures for Western Balkans, Moldova and Ukraine amount to a further 3- 9 million ha. Research work in S2Biom has estimated that a total of 32.4 million ha can be available in Europe by 2030.

This comprises of 25.2 million ha of land with marginal conditions and 7.2 million ha of land which will be released from traditional cropping due to low economic competitiveness of existing production systems[78].

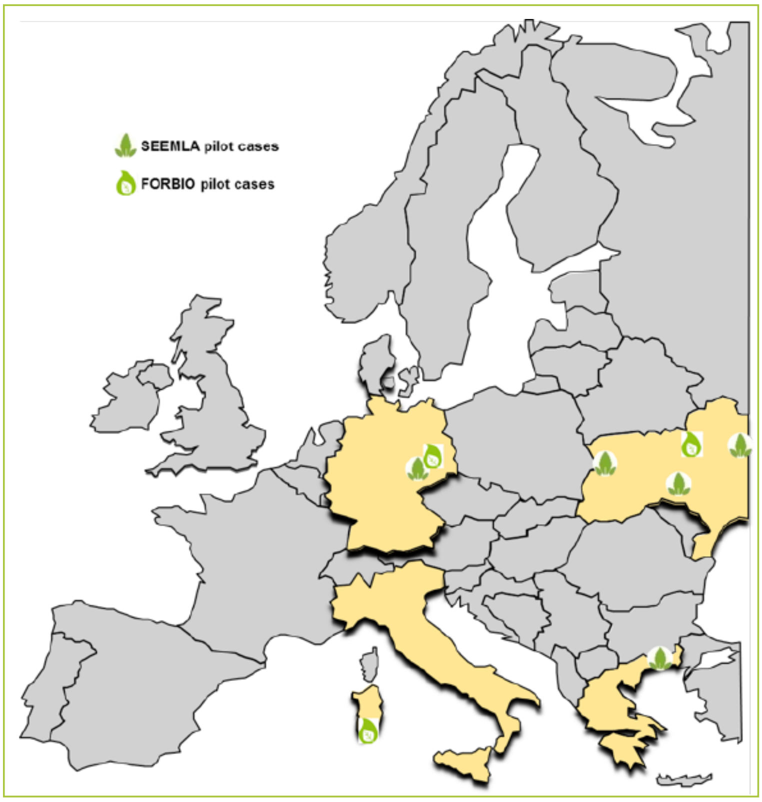

Figure 6 *Schematic illustration of pilot cases and their relative location in the H2020-funded projects SEEMLA and FORBIO.*

Demonstration cases in Europe

At the current stage (March 2018), in case of FORBIO and SEEMLA, pilot studies are still ongoing, and final calculated yields will be available in the upcoming months. However, first results already showed that in case of Germany poplar and black locust are suitable for being grown on marginal land, especially on post-mining sites and areas with very poor soil quality. Beside this, willows as well as herbaceous crops as giant reed or miscanthus are appropriate crops for being grown under climate conditions in Ukraine, but also in Germany and Italy, whereas in addition willow can be also grown under stagnic (temporarily or permanently water saturated) soil conditions. Deriving from such findings, it is the main aim of the projects [FORBIO and SEEMLA] to offer recommendations to farmers and foresters, who are interested in growing energy crops on marginal land, providing guidelines for most suitable and promising (cost-efficient and high yields) crops and the respective land management.

In **figure 6** the location of pilot cases in the projects SEEMLA and FORBIO are illustrated, including Germany, Italy, Ukraine and Greece. In detail, experiences in Germany illustrate positive scientific findings and agricultural practice for producing biomass on highly degraded post-mining sites. Investigations by Quinkenstein et al. (2012)[79] showed that planting black locust (Robinia pseudoacacia L.) on severely disturbed post-mining areas despite low soil fertility can produce high biomass yield with the creation of beneficial land-use system. In SEEMLA, e.g. black locust or poplar are grown on post-mining sites and used for land reclamation purposes and as bioenergy crop. In case of FORBIO and the investigated site in Italy (Sardinia), giant reed (Arundo donax L.) among perennials and milk thistle (Silybum marianum L. Gaertn.) among annuals, are the most appropriate energy plants to be grown on contaminated marginal lands, and most tolerant towards droughts.

Investigations by Fernando and Oliveira (2005)[80] showed that growing bioenergy crops on marginal land might not only affect the level of the yield but also its quality. Production of bioenergy crops on the soils of contaminated area may cause accumulation of heavy metals and other contaminants, hence compromising biomass quality.

Dauber et al. (2012) identified that accumulation of contaminants in the plants depends on the level of yield. Lower yield concentrate nutrients, such as nitrogen, compromising its use for combustion purposes, due to higher nitrogen oxides emissions. Hence, contents of contaminated substances need to be controlled and documented according to national and EU-regulations, in order to exclude or at least minimize as much as possible the risks for the environment and human being.

Thus, about 100 million to 1 billion ha (Worldwatch Institute, 2006) of marginal lands in the world are potentially available with the ability to produce 1.4 to 2.1 billion tons of biomass. Anderson-Teixeira et al. (2009)[81], Blanco-Canqui (2010)[82], and Dauber et al. (2012) consider lignocellulosic crops such as switchgrass (Panicum virgatum L.), miscanthus, and short-rotation woody crops as the most suitable for being grown on marginal lands, functioning as basic substrate for second generation biofuels.

The main challenge for the EU and stakeholders, i.e. especially foresters and farmers will be to identify the most productive plant species that can be grown on the various types of marginal land under different climate conditions, and to develop both an attractive and economically efficient policy framework that supports the bioenergy crops production on marginal lands, i.e. by incentives.

Cultivation of willows at abandoned farm land close to Volyn (Ukraine). Source SEEMLA Project/Werner Gerwin

R&I RECOMMENDATIONS

METHODOLOGICAL APPROACHES, DATASETS AND DATABASES FOR

- the identification of marginal land (in field, in the laboratory, GIS-tool) and their yield potential (bioenergy plants); à cf. [pre-]calculation of yields (short and mid-term)
- the land management and use of marginal land under given climatic conditions; (mid-term)
- recommendations for farmers and foresters, as well as to decision makers/policy makers (short to mid-term)
- [Pre-]Calculation of yields – collecting data | statistics; estimation of yields on marginal land sites under given climatic conditions; (short and mid-term)
- Transport & Logistics: creating an infrastructure of logistic centers with products grown in marginal land. (short and mid-term)

POLICIES

- Creating a unified policy framework, and attractive supporting systems for farmers and foresters using marginal land for no- food uses (mid-term)
- Instruments for creating new jobs in the field of bioenergy | biomass production in marginal land (short-term with mid-/long-term effect)
- Creation of incentive programs; financial support for farmers and foresters; (short and mid-term)
- Marketing: marketing strategies; selling products produced in MagL; (short and mid-term)

ENVIRONMENT AND ECOLOGY

- Closing nutrient cycles: reduction of N and P emissions à e.g. Agroforestry in shore areas | river/lake catchments; NO3 reclamation/reduction in groundwater. Mechanisms? Quantification? (short and mid-term)
- Reclamation of [heavily] degraded land by e.g. growing SRC in marginal land, e.g. poplar or robinia; reduction in erosion, reduction in pollutants etc. (mid-term)
- Investigation of effects on ecosystems; (mid-term)
- Sustainable use of marginal land with e.g. an increased demand in water and nutrients for achieving a considerable yield of bioenergy crops at the same time – and how to avoid iLUC? (mid-term)

3 BIOMASS SUPPLY AND COST SUPPLY ASSESSMENTS

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The aim of this section is to:

- provide an overview of research on biomass cost supply based on selected studies including Biomass Futures, Biomass Policies, BioTrade2020 plus, BioSustain, S2Biom, and the recent study for Research and Innovation perspective of the mid- and long-term Potential for Advanced Biofuels in Europe, etc.);
- highlight key opportunities and address major challenges
- provide a set of R&I recommendations

Wherever appropriate, the evidence presented is further detailed for agricultural, forest and biowastes.

Overview of research

Since early 2000, several biomass assessment studies were delivered at EU and individual Member State level. Most of them were driven by the increasing demand of both policy and industrial actors in the bioenergy and biofuels sectors. As such, the key assumptions used to estimate the available biomass and its costs as well as the respective units in which they have been expressed have been strongly related to energy. Their approaches have also been very different; thus, their results are difficult to compare and interpret.

Responding to this challenge, the European Framework Programme for Research funded the BEE project[83] in 2008. The work performed in it provided a state-of-the-art overview for biomass resource assessments in Europe and developed numerous generic approaches, definitions and a classification of biomass feedstock types to improve the accuracy and comparability of future biomass resource assessments.

From 2010 onwards, research broadened to ensure sustainability criteria are well integrated in the scenario assumptions and include biomass uses for bio-based materials, evaluate potential synergies and competition. To accomplish this, both units and respective assumptions have been modified to reflect the biophysical values of biomass supply potentials, addressing land use, displacement effects and potential climate change impacts.

Geographic disaggregation has also been a research topic that significantly improved during the last ten years in the analysis of biomass cost supply potentials. Until 2012, the assessments were made at national level (NUTS0[84]).

The Biomass Futures project[85] used the methodology from the BEE project and provided a detailed Biomass Atlas[86] for all European Union countries at NUTS2- State level (comprises of 273 geographical subdivisions of countries in the European Union). The Atlas provided spatially detailed and quantified overview of EU biomass potential considering the main criteria determining biomass availability from agricultural and forest feedstocks.

During the period 2013-2017, research work has capitalised on the respective databases and was further developed within the following initiatives:

BIOMASS POLICIES[87]: the work built on the datasets from Biomass Futures in terms of detailed cost supply information and considered competition from known conventional uses (animal feed

Straw bales at biomass power plant in Denmark.
Source: ETA Florence

and food). This work was also performed for all biomass feedstock types (oil, starch, lignocellulosic) with geographic disaggregation at NUTS2-State level.

S2BIOM[88]: the research work built on the BEE, Biomass Futures and Biomass Policies projects and focused on fifty (50) lignocellulosic biomass types. It covered all Europe, expanded geographic coverage of the biomass supply assessments to non-EU countries in Western Balkans, Moldova, Ukraine and Turkey and improved the level of disaggregation to the NUTS3 level in the EU countries, FYR of Macedonia, Serbia, Ukraine, Turkey, which represent 1,450 districts across Europe.

BIOSUSTAIN PROJECT[89]: Sustainable and optimal use of biomass for energy in the EU beyond 2020 – An Impact Assessment: the work built on the datasets from the Biomass Policies project and further assessed the environmental, economic and social impacts of plausible policy options to ensure the sustainable production and use of bioenergy in the EU beyond 2020, in respect to the increasing demand for biomass within the bioenergy sector and in other sectors like material use and biochemistry.

RESEARCH AND INNOVATION PERSPECTIVE OF THE MID- AND LONG-TERM POTENTIAL FOR ADVANCED BIOFUELS IN EUROPE[90]: The overall goal of the study was to contribute to future policy developments in advanced biofuels. It aimed to feed into the discussion by the DG Research and Innovation on the role of research and innovation for advanced biofuels. The study had three specific objectives, namely to:

- provide an assessment of the potential for research and innovation for biomass feedstock for energy for the time horizons of 2030 and 2050;
- assess the potential contribution of advanced biofuels for achieving the EU 2020 targets;
- compare different fuel options for transport.

Key opportunities

BROAD SPECTRUM OF BIOMASS FEEDSTOCKS Europe offers a diverse portfolio of feedstocks that are produced as primary or secondary products from agriculture, forestry and waste sectors.

CROP YIELD AND QUALITY TRAIT IMPROVEMENTS both conventional and dedicated non-food crops will have significant yield and quality trait improvements during the next decades. This, in many cases, will enable them to have low iLUC and GHG implications on a value chain perspective, to adapt to marginal land conditions (drought, wetness, low fertility, etc.) and to produce more residues per unit of land.

IMPROVED SUSTAINABILITY PRACTICES bioenergy applications have already established concrete sustainability criteria with strict principles. Encouraging the uptake of more biomass feedstocks will facilitate further transfer of knowledge and experience for sustainable practices to the local implementation level of new plants.

RURAL DEVELOPMENT using biomass feedstocks for bioenergy and biobased materials offers opportunities for farmers and forest owners across European regions to increase their annual income and maintain their jobs on a year-round basis.

Table 1 provides a more detailed overview of feedstock specific opportunities from their potential use for bioenergy.

FEEDSTOCK TYPE	OPPORTUNITIES
Grain crops	Annual crops create flexibility for farmers; amounts destined for energy could potentially be diverted back to the food market in times of shortages. Crop commonly known to farmers; supply chain already exists.
Sugarbeet	
Oil crops	
Straw	In regions with low animal raising activities, using straw will offer new market outlets while in regions with traditional straw field- burning practices, the use of this feedstock through efficient energy systems will offer significant environmental benefits.
Fruit tree pruning & orchards residues	Providing additional market opportunities to farmers for residues (especially small diameter, branches, etc.) that remain unused or are burnt in open-field fires. Termination and replacement of exhausted orchards.
By-products and residues from food and fruit processing industry	Onsite, low cost feedstock for replacing fossil fuel in agro-industries.
Solid and liquid manure	Extracting energy from manure, especially in regions with excess of manure can complement manure treatment and, in many cases, may reduce N-surplus and N-leaching if manure/dried digestate is exported.
Landscape care wood & biomass from road side verges	Management of landscapes can improve biodiversity and offer additional income to local populations.
Primary wood residues	The use of onsite harvest residues results to a higher harvest of biomass (products and energy) per hectare of land.
Secondary wood residues	Indirectly this results in a more efficient use of the harvested forest products
Biowastes	Exploiting biowastes for energy purposed can lower risk of water pollution especially in regions where landfill is avoided or reduced.
Dedicated biomass crops	Higher land productivity when using marginal lands (compared to reference); in case of agricultural lands there generally is also a gain (but not necessarily) at least in terms of biomass production/ha as most perennials are high yielding. Better environmental performance compared with conventional crops (esp. if the latter needs intensive fertilization to stay competitive despite use of poor marginal land).

***Table 1** Feedstock specific opportunities.*

Research challenges

Though significant effort has been placed in assessing biomass potentials and cost supply issues there are still challenges in interpreting and understanding the data and projected figures. These include clarity for biomass feedstock types, the potential restrictions and risks for its mobilisation, the typology of biomass potentials and data availability.

BIOMASS FEEDSTOCK TYPES

Most of the reviewed studies have divided biomass feedstocks per source of origin, i.e. agricultural, forest and biowaste derived feedstocks.

However, as these categories are broad, several sub-categories are defined in the different studies to provide a more detailed analysis for the potentials. This factor is an important difference among the studies and results into different interpretations for the various potentials. In the case of dedicated crops the fact that they represent a feedstock type that is directly related to land use and restrictions for its availability.

- Agricultural biomass usually includes i) straw, ii) fruit tree pruning & orchards residues, iii) landscape care wood, iv) biomass from road side verges, v) solid & liquid manure and vi) by-products and residues from food and fruit processing industry.
- Forest biomass usually includes i) stemwood, ii) primary residues from forestry production and iii) secondary residues from wood industries (sawmill and other wood processing).
- Biowastes are defined as "biodegradable garden and park waste, food and kitchen waste from households, restaurants, catering and retail premises and comparable waste from food processing plants" (Waste Framework Directive (2008/98/EC).
- Dedicated crops: these comprise of both conventional oil, sugar and starch crops as well as lignocellulosic woody and grassy crops that can be cultivated for non-food purposes.

Table 2 provides an outlook of the main feedstock categories that have been included in the recent assessments and describes the key restrictions and potential risks that may hinder their mobilisation.

TYPOLOGY OF BIOMASS POTENTIALS

The classification in types of biomass potentials helps to understand what information is presented in each study and appreciate how the projected figures are estimated. For instance, some biomass types show high technical potentials while their economic potential is rather limited due to the high costs of extraction and transport. Table 3 provides the definitions for the types of biomass potentials as they have been identified by the BEE project.

DATA AVAILABILITY, HOMOGENEITY AND VALIDITY FOR THE BASELINE DATASETS

The availability, homogeneity and validity of data relies highly on the official statistics since these are the initial data required for biomass assessments from all sectors (agriculture, forestry and wastes). In the countries where national statistics are updated on regular basis and appropriate methodologies are developed in the official statistical systems, there are no significant problems and challenges regarding the quality and reliability of the initial data. This is the case for all European Union Member States.

However, problems with the reliability of the initial data exist in some of the non-EU countries. Within their official statistical systems there is no provision for collection, processing and publishing the data. In these countries, data below the national averages and market prices/costs are particularly scarce as well. In such cases, data collection is restricted and the approach followed so far is based on detailed validation of the required datasets and indicators by national experts and comparison with local studies. Table 4 provides an overview of the main data sources and challenges for biomass assessments per feedstock category.

RESIDUE TO MAIN PRODUCT AND TECHNICAL AVAILABILITY RATIOS

The estimation of the theoretical residue yield per hectare depends strongly on the biomass feedstock type and local practices for its management, harvesting and storage. This is a challenge in biomass supply assessments and requires validation of indicators found in literature from local experts.

Similarly, the technical availability ratios consider technical limitations related to the biomass feedstock physiology, the harvest/ collection index and the prevailing climate and soil conditions in each region. There are several factors that limit the amount of biomass available to be collected and further processed.

These include the harvesting equipment, the feedstock type, growth pattern and variety, the harvest index (related to both growth rates and management practices) as well as losses from lodging (e.g. crops flattened by wind or rain), deforestation, forest fires, etc.

	FEEDSTOCK TYPE	DESCRIPTION	RESTRICTIONS&RISK[91]
Agriculture	Liquid manure	Liquid manure produced in stables in which the manure is converted to slurry and stored in liquid manure storage tanks.	High moisture content reduces energy volume in transport. Competition with use as fertiliser (especially in regions with shortage of manure) When digestate is used as fertiliser instead of liquid manure, the carbon content is reduced.
Forestry	Stemwood	Stemwood from thinnings and final fellings	Soil quality loss, biodiversity risks, Carbon debt
	Primary wood residues	Early thinning stems and crown, logging residues of final fellings and thinnings, stump extraction final felling (only where removal of these is common practice)	Biodiversity loss when harvesting forest residues through loss of dead wood and stumps which is negative for forest plant species diversity and soil fauna. Increased risk of soil erosion, in particular when stumps are harvested.
	Secondary wood residues	These consist of sawmill by-products like bark, offcuts, sawdust and other industrial residues and black liquor	Some clean wood residues and sawdust can also be used by the paper or wood panel industry.
Biowastes	Household and non-household wastes	Paper carboard, Wood waste, Animal & mixed food waste, Vegetal waste, Municipal solid waste (MSW), Common sludge	Restrictions from recycling and re-use for materials
Dedicated crops	Perennial grasses and Short Rotation woody crops	Ligno-cellulosic perennial and woody crops grown on existing agricultural lands, but also suitable to be grown on lower quality lands that can be defined as 'marginal' and abandoned lands. They are plantations with a lifetime of 15 to 20 years and the biomass harvest takes place at a yearly basis starting from the 2nd (in perennial grasses) and 4th (in woody crops) year onwards.	Risk for loss of semi-natural farmland habitats, direct land use and landscape structural changes which can have negative but also positive impacts for biodiversity.

Table 2 Main feedstock categories in recent biomass cost supply assessments, restrictions and risks for their mobilisation.

TYPE OF POTENTIAL	DEFINITION
Theoretical potential	It is the overall maximum amount of terrestrial biomass which can be considered theoretically available for bioenergy production within fundamental bio-physical limits. In the case of biomass from crops and forests, the theoretical potential represents the maximum productivity under theoretically optimal management taking into account limitations that result from soil, temperature, solar radiation and rainfall. In the case of residues and waste, the theoretical potentials equal the total amount that is produced.
Technical potential	It is the fraction of the theoretical potential which is available under the regarded techno-structural framework conditions with the current technological possibilities (such as harvesting techniques, infrastructure and accessibility, processing techniques). It also takes into account spatial confinements due to other land uses (food, feed and fibre production) as well as ecological (e.g. nature reserves) and possibly other non-technical constraints.
Economic potential	It is the share of the technical potential which meets criteria of economic profitability within the given framework conditions.
Implementation potential	It is the fraction of the economic potential that can be implemented within a certain time frame and under concrete socio-political framework conditions, including economic, institutional and social constraints and policy incentives? Studies that focus on the feasibility or the economic, environmental or social impacts of bioenergy policies are also included in this type.
Sustainable implementation potential	It the result of integrating environmental, economic and social sustainability criteria in biomass resource assessments. This means that sustainability criteria act like a filter on the theoretical, technical, economic and implementation potentials leading in the end to a sustainable implementation potential. Depending on the type of potential, sustainability criteria can be applied to different extents.

Table 3 *Types of biomass potentials according to BEE project.*

	FEEDSTOCK	DATA SOURCES	CHALLENGES
Agriculture	Grain crops	Eurostat and national agricultural crop and land use statistics. Models like CAPRI, GLOBIOM, AGLINK-COSIMO, POLES, RAUMIS, CLUE etc.	Variability in yields and performance which depends on soil, ecology and crop selection.
	Sugarbeet		
	Oil crops		
	Straw	Eurostat and national agricultural crop and yield statistics. CESAR, CENTURY, MITERRA models	Allocation factors for competing markets and a good outlet is to work with CAPRI projections. CAPRI is the key model which predicts the EU markets and production responses at the regional level for the whole EU, western Balkans, Turkey and Norway. It is the best source of information available that gives a plausible overview taking account of the specific diverse regional circumstances in the EU, of what land-use changes can be expected by 2020 and 2030 and the extent to which they can be related to dedicated bioenergy cropping.
	Fruit tree pruning & orchards residues		Estimating the amount of pruning residues delivered by fruit trees and orchards is rather challenging. There is wide variation in type of trees, shrub forms used, varieties and traditional practices. For these crops there is less understanding of the relation between yield levels of the main crop, 'fruit', and the residue potential. There have been several publications providing residue-to-yield ratios for the different permanent crops, especially covering the Mediterranean region, but the variation is very large[94,95,96,97].
	Landscape care wood	Land use and land cover high resolution data	Residue ratios are highly variable across types of feedstocks.
	Biomass from road side verges	Road network data	
	By-products and residues from food and fruit processing industry	Eurostat and national crop statistics, literature	
	Solid manure	Eurostat and national agricultural statistics, GAINS , FADN, SAPM	Several opinions for optimal use of manure for fertilisation of soils in agriculture. Variability depends on soil, ecology and crop selection.
	Liquid manure		
Forestry	Primary wood residues	National forest inventory data, FAOSTAT, models like EFISCEN, GLOBIOM, EFI-GTM	The logging residue potential depends on the maximum allowable volume of final fellings and the species composition. This information is quite challenging to obtain, specifically in relation to the species composition of the stemwood harvest in time. One can therefore only assume a similar species composition for every harvest year unless more specific species composition data are available from the forest inventory.
	Secondary wood residues	FAOSTAT, EUwood	Country specific data on recovery rates, sawmill sizes and sawmill size structures are partly available. The EU wood study (Saal, U, 2010) an extensive assessment was done of the availability of sawmill by-products and since there is no better study published since then, it is logical to take this as the best example and data source.

Table 4 *Potential data sources per feedstock category[93].*

Biomass cost supply

Biomass cost supply assessments vary across the reviewed studies. However, their ranges are quite close as the main assumptions framing the projected numbers are getting more harmonised and oriented towards the following issues:

- How will sustainability criteria across all bioenergy sectors and feedstocks affect biomass uptake?
- What will be the role of research and innovation in improving biomass availability?

Figure 7 provides an overview of the estimated cost supply (road side cost- no transportation included) ranges for agricultural, biowaste and forest feedstock types.
The box highlighted in green in figure 7 illustrates the amount of residual feedstocks from agriculture and biowastes that have estimated costs up to 3 €/GJ. The boxes on the right illustrate the type of feedstocks that are grouped within each cost band.

Residual feedstocks from agriculture and biowastes comprise are in the low-cost band (0-3 €/GJ) and amount almost 3,000 PJ. In this band, liquid manure costs are set to zero while road side verge grass has an average cost of 0.5 €/GJ; forage crops 1.5 €/GJ; solid manure 2.2 €/GJ, landscape care wood, prunings, olive pits and wastes at 2.5 €/GJ.

Straw, primary and secondary wood wastes as well as lignocellulosic biomass crops (woody and perennial grasses) comprise the middle-cost band (4-7 €/GJ). The first three categories have an average cost of 4- 4.5 €/GJ while biomass crops range from 5-7 €/GJ depending on the country and crop species.

Finally, grain crops (cereals, maize), sugarbeet and oil crops comprise the high- cost band (12-16 €/GJ). The first two categories have an average cost of 8-10 €/GJ while the cost of oil crops ranges from 12-16 €/GJ.

VARIABILITY OF COST SUPPLY AT NATIONAL LEVEL

Costs and respective prices (where applicable) for all feedstocks vary among Member States. Since the understudy biomass feedstocks are land based, this asset is one if the major cost factors and its variance among countries reflects also the production costs for many crop and residual biomass types. Figure 8 is based on EUROSTAT data land and presents cost values across Member States in €/ha/year. Italy and the Netherlands have the highest land rent costs in EU followed by Spain, Sweden, Belgium, Greece, Poland, Portugal, Austria, France and Germany. Land rent costs below 200 €/ha/year can be observed in Czech Republic, Estonia, Latvia, Lithuania, Slovakia and Slovenia.

An example of land-based biomass feedstock with high presence in EU is straw. Currently it is the largest agricultural biomass residue in practically

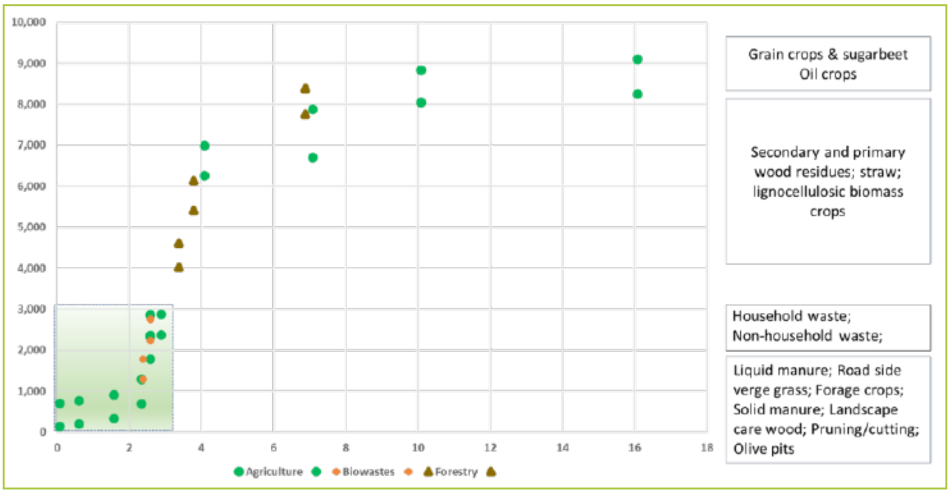

Figure 7 Sustainable biomass cost supply in EU by 2030 (in PJ- €/GJ) (adapted from Biomass Policies and S2Biom databases).

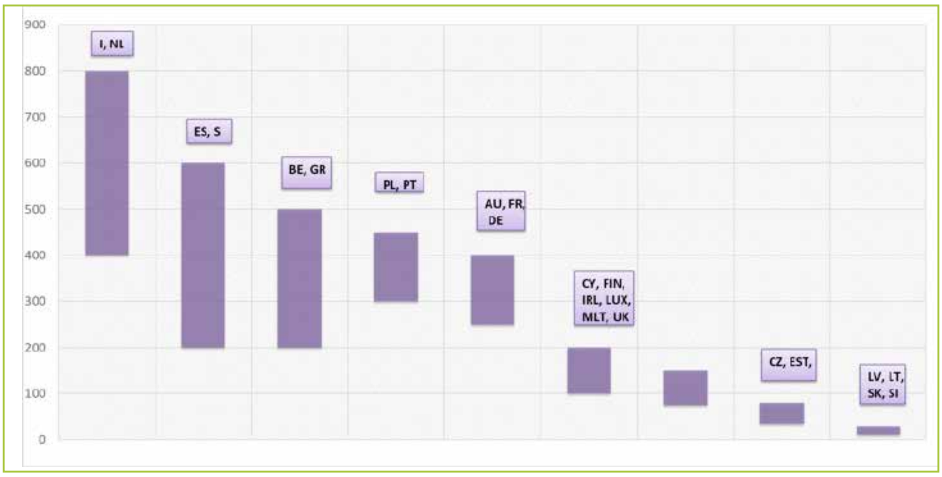

Figure 8 Land rent cost ranges (low-high) in €/ha/year across EU Member States.

RECOMMENDATIONS FOR R&I ACTIONS

EVIDENCE FOR COMPETITION AND RESOURCE EFFICIENCY

- Assess "cross- sector" resource availability at regional level with guidelines for resource efficiency and competition (short to mid-term)
- Identify "hot spots" of bioenergy and biobased materials. Assess the regional balance of biomass supply with respective demand. The idea would be to match biomass potentials with the best local solution (short term)

SUSTAINABILITY

- Standard setting with criteria and indicators that correspond to residue ratios, technical availability factors and sustainability criteria (short to mid-term)
- Define and tailor sustainability criteria for resource efficient biomass mobilisation practices; per feedstock type and per ecological zone depending on the agro-climatic conditions (short to mid-term)

REGIONAL DEVELOPMENT

- Understand regional and local mobilisation patterns and improve uptake of residual feedstocks and biowastes (short to mid-term)
- Raising awareness is rather important (short term)

all EU countries. The main source of straw is cereals, but there are EU regions that also have large potentials of other types such as grain maize stover in France, Romania, Hungary and Italy or rape and sunflower stubbles in France and Germany.

Straw also have competing uses for animal feed and bedding, mushroom cultivation., etc. The most recent studies[87, 88, 89] calculated the competing uses based on livestock numbers and mushroom production levels.

In terms of geographic distribution among Member States, countries with a clear straw deficit are Cyprus, Ireland, Malta, Netherlands and Portugal. On the other hand, countries with large straw availability and limited competing use levels are Germany, France, Bulgaria, Czech Republic, Poland, Hungary and Romania[87].

Both cereal straw and grain maize stover es have at the moment low utilisation rates for energy and biofuels[100]. Figure 9 below provides an overview of the straw prices (low, average and high) in Member States.

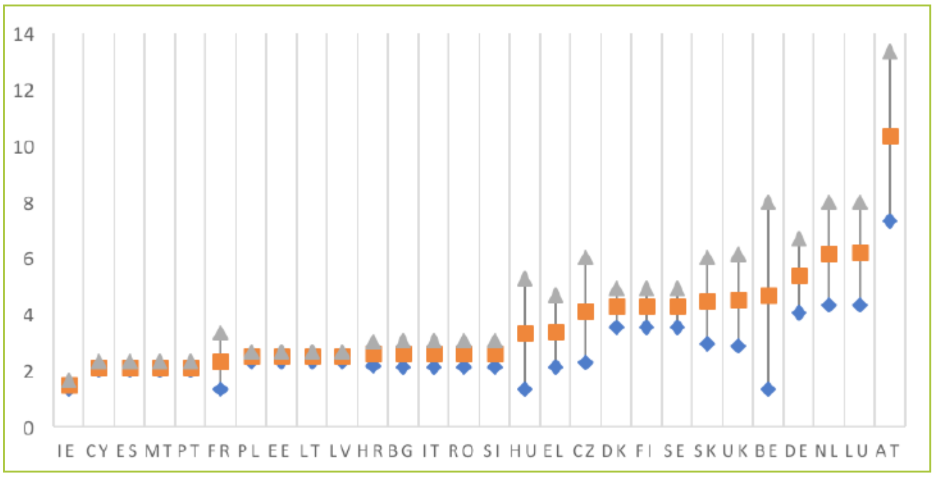

Figure 9 High, average and low straw prices (€/GJ) in EU Member States (adapted from Biomass Policies and S2Biom databases).

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4 CERTIFICATION & STANDARDISATION

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The aim of the work will be to:

- provide an overview of the key issues around biomass certification and standardisation issues, and
- link potential biomass feedstocks to ongoing activities in CEN and ISO.

This part of the paper summarizes the ongoing standardisation work of biomass and sustainability.

Table 5 lists the ongoing standardisation committees (TC) under European Committee for Standardisation (CEN[101]) and International Organisation for Standardisation (ISO[1]) for solid and liquid biofuels, and sustainability. It also lists the main research questions for standardisation.

What is a standard?

A standard is a document, designed for common and repeated use, to be used as a rule, guideline or definition. It is both consensus-built and approved by a recognized body.
Standards should be based on the consolidated results of science, technology and experience.

What is certification?

Certification is third-party testimony (i.e., issue of a statement) that specified requirements related to products, processes, systems or persons have been fulfilled[103].

CURRENT STATE OF BIOMASS CERTIFICATION

Biomass is used for liquid, gaseous and solid bioenergy carriers and also as raw material for biobased products. Certification and standardisation should take all users into account and there should not be contradictive standards. Other challenge is that work is carried under CEN and ISO. Then work is carried out under Vienna agreement then ISO standards are published in Europe as EN ISO standards.

Most of the standards are product standards and do not include specification of raw materials. Only fuel specification and classes standard series EN ISO 17225 have also specification of raw material (origin and source). Especially for woody biomass specification of raw material indicate the properties e.g. sawdust without bark has low ash content compared to logging residues, which can include also soil.

Standards are created by bringing together all interested parties such as manufacturers, consumers, and regulators of a particular material, product, process or service. All parties benefit from standardization through increased product safety and quality as well as lower transactions costs and prices. An important objective of standardization is to remove barriers in the European market for goods and services.

Opportunities

Harmonisation of methods as the feedstock base for advanced biofuels and bioenergy is broadened to include various residual and waste type of materials.

Challenges

The main challenge is that each standardisation group for biomass and bioenergy is working separately, not looking standardisation bodies dealing with same raw material. This results in different requirements and definition for different purposes.

COMMITTEE	NAME	REMARKS
CEN/TC 335	Solid biofuels	Work has finished and new standards will be published under ISO/TC
ISO/TC 238	Solid biofuels	Vienna agreement to be followed and standards will be published in Europe as EN ISO standards (raw materials can be specified)
CEN/TC 19	Petroleum products, lubricants and related products	WG 41 for pyrolysis oil (Mandate M525), this bio-oil according to REDII, FAME etc.
CEN/TC 343	Solid recovered fuels	Solid recovered fuels prepared from non-hazardous waste. Include wood waste. Work is continued under ISO/TC 300
ISO/TC 300	Solid recovered fuels	Standardization of solid recovered fuels, from point of acceptance of material to be recovered to point of delivery, prepared from non-hazardous waste to be used for energy purposes, excluding fuels that are included in the scope of ISO/TC 238 (Solid biofuels) and ISO/TC 28 (Petroleum and related products, fuels and lubricants from natural or synthetic sources).
CEN/TC 383	Sustainably produced biomass for energy applications	No mandate from the Commission, include only sustainability of liquid biofuels
ISO/TC 248	Sustainability criteria for bioenergy	Sustainability criteria for production, supply chain and application of bioenergy
CEN/TC 411	Biobased products	TC is to develop standards for bio-based products covering horizontal aspects. This includes a consistent terminology for bio-based products, sampling, bio-based content, application of and correlation towards LCA and sustainability of biomass used, and guidance on the use of existing standards for the end-of-life options.
ISO/PC 287	Chain of custody of forest-based products – Requirements	Set requirements for a chain of custody (CoC) of wood and wood based products and lignified materials other than wood (such as bamboo, cork). Also forest certification is taken into account.

Table 5 Overview of standardisation committees under CEN and ISO for solid and liquid biofuels, and sustainability.

STANDARD NUMBER	STANDARD NAME	REMARKS
EN ISO 17225-1[a]	Solid biofuels - Part 1. General requirements	Specify raw material from woody, herbaceous, fruit and aquatic biomass. Include also used wood (post-consumer wood if "clean") Quality tables for pellets, briquettes, wood chips and hog fuel, firewood, sawdust, shavings, straw bales, bark, energy grain, olive residues, fruit seeds, charcoal, thermally treated biomass (e.g. torrefied) and general Table for other biomass Each property can be selected separately.
EN ISO 17225-4[a]	Solid biofuels - Part 4. Graded wood chips	Classes A1, A2, B1 and B2 A1 and A2 only for virgin wood (natural wood), B1 for short rotation wood B2 can include also chemically untreated used wood.
ISO/TS 17225-8	Solid biofuels - Part 4, Thermally treated densified biomass fuels	Covers pellets and briquettes manufactured by torrefaction, steam explosion and hydro thermal carbonisation. Raw material can be woody or herbaceous biomass.
EN 15359[b]	Solid recovered fuels. Specifications and classes	Specify quality requirements of solid recovered fuels and waste raw materials Under revision to ISO standard.
EN 16900	Petroleum and related products — Fast pyrolysis bio-oils for industrial boilers – Requirements and test methods	Requirements and test methods for fast pyrolysis bio-oils. For industrial boilers (≥ 1 MWth) Raw material can specified according to SFS-EN ISO 17225-1
CEN/TR 17103	Petroleum and related products — Fast pyrolysis bio-oils for stationary internal combustion engines — Quality determination	Requirements and test methods for fast pyrolysis bio-oils. For Internal Combustion Engines (ICE). Report
EN 16640	Bio-based products - Bio-based carbon content - Determination of the bio-based carbon content using the radiocarbon method	Test method for determination of bio-based carbon content
EN 16785-1	Bio-based products - Bio-based content - Part 1: Determination of the bio-based content using the radiocarbon analysis and elemental analysis	Test method for determination of bio-based content
EN 16785-2	Bio-based products - Bio-based content - Part 2: Determination of the bio-based content using the material balance method	
EN 16751	Bio-based products - Sustainability criteria	Sets sustainability criteria for biomass and bio-based products

Table 6 *List of main standards specifying raw material or fuels and sustainability.*

STANDARD NUMBER	STANDARD NAME	REMARKS
CEN/TS 16214-2	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Principles, criteria, indicators and verifiers - Part 2: Conformity assessment including chain of custody and mass balance	Set sustainability criteria for biofuels and bioliquids. Part 2 is conformity of custody and mass balance
EN 16214-3	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Principles, criteria, indicators and verifiers - Part 3: Biodiversity and environmental aspects related to nature protection purposes	Set sustainability criteria for biofuels and bioliquids. Part 3 is for biodiversity and environmental aspects
EN 16214-4	Sustainability criteria for the production of biofuels and bioliquids for energy applications - Principles, criteria, indicators and verifiers - Part 4. Calculation methods of the greenhouse gas emission balance using a life cycle analysis approach	
ISO 13065	Sustainability criteria for bioenergy	Sets sustainability criteria for biomass and bioenergy. Was the basis for EN 16751
EN 16760	Bio-based products – Life cycle assessment	Includes further guidance and requirements for when EN ISO 14040 and 14044 are used for bio-based products
ISO 38200	Chain of custody of wood and wood-based products	A chain of custody system is a process by which information about materials can be tracked throughout the entire or parts of the supply chain.

Table 6 *List of main standards specifying raw material or fuels and sustainability.*

- *A - ISO/TC238 has prepared test methods, sampling and sample preparation and terminology standards separately and they are listed at https://www.iso.org/committee/554401/x/catalogue/*
- *B- CEN/TC 343 and ISO/TC 300 has also prepared test methods, sampling and sample preparation and terminology standards separately and they are listed at https://standards.cen.eu/dyn/www/f?p=204:32:0::::FSP_ORG_ID,FSP_LANG_ID:407430,25&cs=1E692895E0FA13AE68B9FA01D5A630ED7*

R&I RECOMMENDATIONS

- How certification and standardisation can take different feedstock user sectors (energy and raw material) into account that there are no contradictive standards?
- How standards can meet industrial requirements for all user sectors – interdisciplinary research of quality requirements needed?
- Do we need also standards for classification of biomass feedstock (usually not included in product standards)?
- How certification for final products and bioenergy carriers can meet sustainability, GHG savings etc. requirements without heavy bureaucracy?

NOTES

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103. Adapted from ISO/IEC 17000, 2005, Definitions 5.2 and 5.5.

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