S2Biom

Delivery of sustainable supply of non-food biomass to support a
"resource-efficient" Bioeconomy in Europe

S2Biom Project Grant Agreement n°608622

# D8.2
# Vision for 1 billion dry tonnes lignocellulosic biomass as a contribution to biobased economy by 2030 in Europe

## November 2016




## About S2Biom project

The S2Biom project - Delivery of a sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe – supports, characterises and quantifies the sustainable delivery of non-food biomass feedstock at local, regional and pan European level through developing strategies and roadmaps that will be informed by a "computerised and easy to use" toolset with updated and harmonised datasets at local, regional, national and pan European level for EU28, western Balkans, Turkey and Ukraine. Further information about the project and the partners involved are available under www.s2biom.eu.

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## About this document

This report corresponds to 'D8.2 Vision for 1 billion dry tonnes lignocellulosic biomass for biobased economy by 2030 in Europe'. It has been prepared by:

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## Summary

The total bioeconomy in Europe already accounts for more than 2 trillion € annual turnover and almost 20 million jobs[1]. These numbers include food, feed and primary production such as agriculture and forestry. The non-food and feed "biobased component[2]" is expected to double by 2030[3].

At the same time, the current market share for advanced, non-food and feed biobased products is already significant and it is growing fast. Consumer awareness and product availability is increasing and innovations will be brought faster to market via initiatives such as the "Biobased Industries Initiative Joint Undertaking[4]", the recent public-private partnership between the European Commission and the industry.

To grow further the biobased economy in Europe requires the mobilisation of domestic biomass feedstocks in a sustainable and resource efficient manner[5] and the transition to advanced conversion technologies and lignocellulosic feedstocks.

S2Biom (www.s2biom.eu ), a European funded project, improved scientific evidence on the availability, cost supply, technologies and framework conditions (policy, financing, sustainability) for lignocellulosic non-food biomass in Europe[6] by 2030. Project partners have developed a Vision statement for an expanded role of sustainable non-food lignocellulosic biomass supply and delivery as contribution to the European biobased economy.

The information presented in this study is based upon new S2Biom-derived knowledge and data as well as a meta-analysis of an inventory of 350 studies covering a period of the last ten years (2005- 2015) and consultations with project partners and external stakeholders. Comparisons have been narrowed (for consistency and harmonised approaches) to Biomass Energy Europe (BEE)[7], Biomass Futures[8], Biomass Policies[9], Wasted[10], EUBIONET[11], Bioboost[12], BIOTIC[13] and recent work in the Energy Community[14].

[1] http://biconsortium.eu/sites/biconsortium.eu/files/news-image/BIC_PressRelease_Bioeconomy2013_3March2016.pdf
[2] Such as chemicals, plastics and biofuels
[3] Bio-Tic project: Market roadmap (2015) - http://www.industrialbiotech-europe.eu/new/wp-content/uploads/2015/10/Market-Roadmap-Final-1-OCT-2015.pdf
[4] http://bbi-europe.eu/
[5] According to the EU 2020 Flagship Initiative Resource efficiency is a way to deliver more with less (natural resources). It increases aggregate economic value through more productive use of resources over their life cycle. It requires using those resources in a sustainable way, within the planet's long-term boundaries. This includes minimizing impacts of one resource's use on other natural resources.
[6] EU28, Western Balkans, Moldova, Ukraine, Turkey
[7] http://www.eu-bee.eu/
[8] www.biomassfutures.eu
[9] www.biomasspolicies.eu
[1010] http://www.theicct.org/wasted-europes-untapped-resource-report
[11] http://www.eubionet.net/
[12] http://www.bioboost.eu/home.php
[13] http://www.industrialbiotech-europe.eu/
[14] https://www.energy-community.org/portal/page/portal/ENC_HOME

## Why a Vision for lignocellulosic biomass in 2030?

**Lignocellulosic biomass is a crucial feedstock for energy and fuels and, in the long run, for biobased products and materials. It is widely available and well suited to a range of conversion routes and applications.**

**Development of a lignocellulosic bioeconomy will require significant investments. Consequently, steps need to be taken to attract adequate funding and create stability and consistency in policy and financing. This also implies access to science-based and transparent information for resource efficient and sustainable biomass value chains.**

**Future market uptake of lignocellulosic biomass relies upon developing common understanding for 'system- wide' impacts and merits by applying common metrics across sectors.**

Lignocellulosic feedstocks in Europe are domestic assets for energy, fuels, biobased products and materials. They provide opportunities for sustainable value chains with limited or no conflict with food and feed markets.

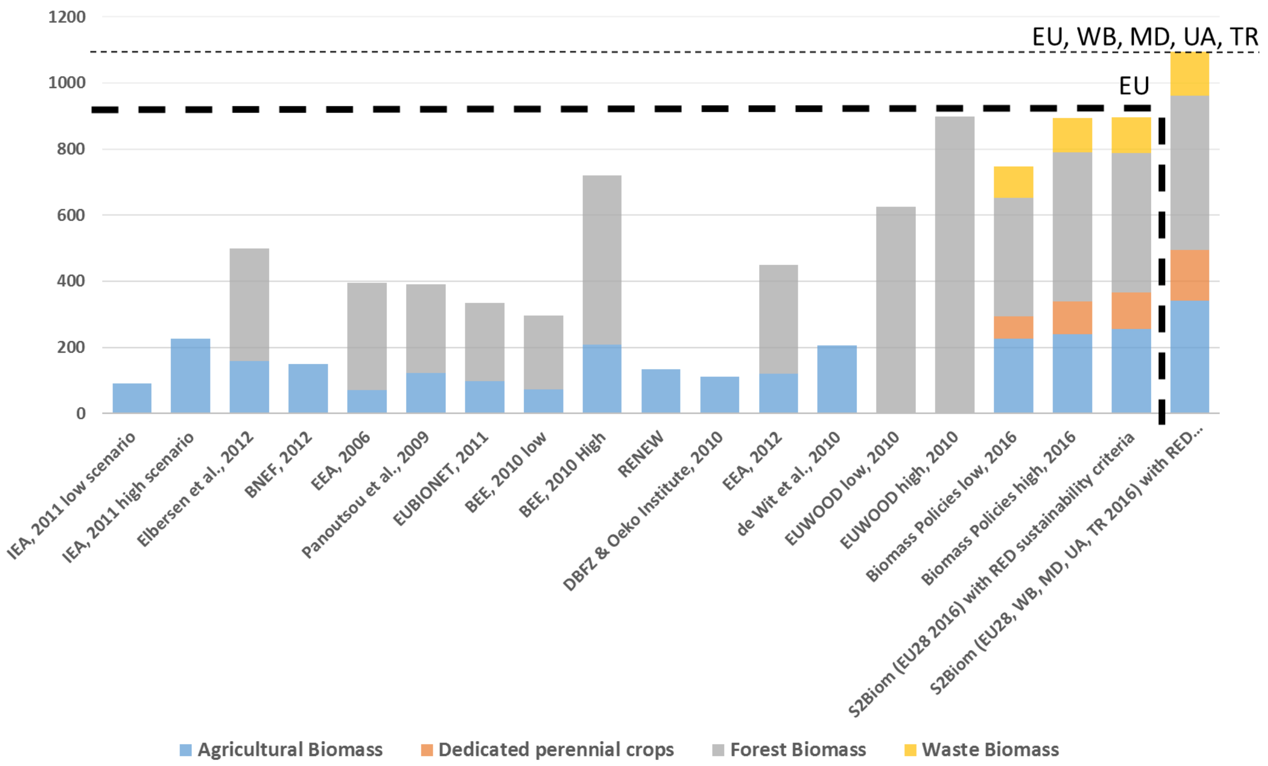



**Figure 1 Estimated potential (,000 dry tonnes per year) for lignocellulosic biomass from agriculture, dedicated perennial crops, forest and waste activities in Europe**

These opportunities are increasingly recognised by both supply (agriculture, forestry, waste) and demand (energy, bio-based products and materials) sectors and the set-up of reliable supply chains is considered pivotal to the success of the biobased economy. This will require innovation in many fields, maybe not always in sheer technology, but certainly in logistics, handling, market development, etc.

Figure 1 provides a comparative overview of S2Biom findings (for EU28 and overall as Europe including Turkey) with several studies for biomass potentials to 2030 and where data are available groups them by feedstock category. All figures refer to sustainably sourced biomass potential. Variance in the presented figures per feedstock category (agriculture, dedicated crops, forest, biowastes) can be attributed to different baseline scenario assumptions, different reference statistics, variant economic assumptions and other factors regarding sustainability issues and mobilisation. An additional factor which results in wider ranges for biomass potentials in the last columns for the Biomass Policies and S2Biom studies is the inclusion of potentials from wastes and dedicated perennial crops.

S2Biom findings confirm that European potential for lignocellulosic biomass is significant. Therefore, the development of a coherent and technically substantiated Vision is required to navigate through several issues including:

- the various market sectors involved - expanding from bioenergy and biofuels to the innovative bio-based materials;
- the wide diversity of biomass types and ranges for potentials;
- the political and industrial expectations for commercialisation of the advanced pathways.

## The markets[15]

**S2Biom model-based projections conclude that a total of 476 million tonnes of lignocellulosic biomass (dry mass) will be needed to fulfil all (including current uses) the expected demand for energy, fuels and biobased materials in Europe by 2030.**

**Low levels of competition can be expected till 2030 between the energy and non-energy biobased sectors in terms of lignocellulosic biomass, since the latter will remain largely oil, sugar and starch based on the short term.**

**Biorefineries in Europe will provide significant potential for synergies and facilitate further mobilisation of lignocellulosic biomass by 2030.**

Lignocellulosic biomass in Europe has been mainly used in traditional markets notably the wood processing industry, pulp and paper industry and heating in domestic and industrial sectors. However, intense political and industrial activity since 2000, with primary aim to reduce harmful climate change impacts, has seen lignocellulosic biomass use expand in new markets including electricity generation (co-firing and CHP), advanced heating (efficient stoves and boilers for both domestic and tertiary sectors), second generation liquid biofuels for transport (automotive and aviation) as well as solid biofuels such as torrefied pellets.

More recently with the launch of the Public Private Partnership (BioBased Industries Initiative or BBI JU[16]) in Europe, lignocellulosic biomass is also expected to have a growing share in advanced pathways for non-energy industries such as biobased chemicals, bio-polymers and plastics and other bio-based materials.

## Bio-based products

Currently the major shares of innovative bio-based products such as polymers, plastics, chemical building blocks, lubricants, solvents and surfactants in Europe are primarily based upon oil, sugar and starch sources with only a small share of natural fibres from wood.

Recent market analysis conducted in Biomass Policies[17] and S2Biom[18] projects indicates that most of these products would still be non-lignocellulosic based by 2030. Based upon

[15] S2Biom model based projections have been performed with RESolve. The RESolve model is an optimization model developed by ECN. The model fulfils given demands for biofuels for transport, electricity and heating using biomass and selected bio-based product value chains in a least cost manner with respect to fossil references. In this optimisation, a variety of policy measures can be included.

[16] http://bbi-europe.eu/

[17] Uslu, A. & van Stralen, J. 2016. Deliverable 4.2(b) Effects of policy framework in the bioenergy market. http://www.biomasspolicies.eu/?page_id=414

[18] http://www.s2biom.eu/images/Publications/S2Biom_D7_2.final.pdf

discussions with industry and model-based[15] projections from S2Biom, the share of lignocellulosic biomass in these markets is expected to reach at least 5%. However, this would still account for only 2-3% of the respective demand for conventional bioenergy and biofuels by 2030.

The market for these biobased products is estimated to develop from 28 billion € in 2013 to 40 billion € in 2020, and up to 50 billion € by 2030. This development represents an annual compound average growth rate (CAGR) of 4% between 2013 and 2030[19]. A study published by EuropaBio in 2016 claims that these products contribute over €30 billion to the EU economy and around 500,000 jobs[20]. It is worth mentioning here that in both studies, the estimated numbers include bioethanol.

### Energy

In 2014, the overall contribution of bioenergy accounted for 110 Mtoe (million tonnes of oil equivalent) representing more than 60% of all renewable energy contribution for EU28, Western Balkans, Moldova and Ukraine. Recent work in S2Biom estimates that demand for all energy markets will reach up to 134.3 Mtoe in 2020 and 185.7 Mtoe domestic biomass in 2030 which totals 56% and 53% of renewable energy contribution respectively). **This figure includes current uses and future demand and implies the use of 422 million tonnes of lignocellulosic biomass in Europe per year by 2030.** The sector has an added value of almost 500,000 jobs and 56 billion € turnover in Europe at present[21].

Electricity: The gross electricity generation from biomass reached 13.6 Mtoe in 2014 accounting for almost 9.5% of total EU gross electricity generation (EC, 2015). S2Biom estimates that demand for electricity will reach up to 20.0 Mtoe by 2020 and 26.3 Mtoe by 2030. **This implies the use of 79 million tonnes of domestic lignocellulosic biomass in Europe per year by 2030. Based upon the S2Biom findings most of these resources will come from wood chip (primary forestry residues).**

Heat: The bioenergy contribution for heating and cooling within the renewable energy sector has the largest share (above 86%) of all RES, currently with 83 Mtoe. For EU28 the respective figure (76 Mtoe) is quite close to the 2020 target of 90 Mtoe. S2Biom estimates that demand for all energy markets in Europe as a whole will reach up to 92.4 Mtoe in 2020 and 128.9 Mtoe in 2030. **This implies the use of 314 million tonnes of domestic lignocellulosic biomass in Europe per year by 2030. Based upon the S2Biom findings most of these resources will come from wood chip (primary forestry residues), landscape care wood and agricultural prunnings.**

[19] http://www.industrialbiotech-europe.eu/new/wp-content/uploads/2015/10/Market-Roadmap-Final-1-OCT-2015.pdf
[20] http://www.europabio.org/industrial-biotech/publications/new-study-shows-industrial-biotech-set-drive-jobs-and-growth
[21] 14th EurObserv'er Report on the State of Renewable Energies in Europe

Biofuels for transport: The share of biofuels in 2014 was 5.4% (13.3 Mtoe). This constitutes about 13% of all bioenergy. There is a need to increase this share[22] by using fuels from lignocellulosic biomass, residues that have no or very low competition with food or land. **This implies the use of 29 million tonnes of lignocellulosic biomass in Europe per year by 2030. Based upon the S2Biom findings most of these resources will come from straw and industrial wood residues.**

[22] SET-Plan – Issues Paper: Strategic Targets for bioenergy and renewable fuels needed for sustainable transport solutions in the context of an Initiative for Global Leadership in Bioenergy

## Current biomass use

### Agricultural biomass[23]

**Approximately 15 million tonnes of agricultural lignocellulosic biomass (dry mass) are currently exploited in Europe while S2Biom estimates that 342 million per year will be available by 2030 under sustainable practices.**

**S2Biom model-based projections indicate that a total of 82 million tonnes agricultural based (including dedicated perennial crops) lignocellulosic biomass will be uptaken by 2030 to fulfil the demand for energy, fuels and innovative bio-based products and materials.**

Nowadays, agricultural biomass is widely used in the biobased economy. However, most applications are “non-lignocellulosic”. A survey[24] made in 2015 reported that companies producing biobased chemicals to date use as primary feedstock non-lignocellulosic biomass like animal fats, vegetable oils, sugar and starch crops.

The most commonly used vegetable oils are rapeseed and palm, followed by coconut, soya bean and castor. The most commonly used natural sugar and starch feedstocks are maize, wheat and sugar beet, which are all edible feedstocks. Respective co-products or intermediates from processing the above feedstocks include glycerol, bioethanol and chemical pulp.

The Bio-Tic project[25] estimated the consumption of the above feedstocks for bio-based products in EU. Based upon these estimates, the use of starch and sugar as biobased material feedstocks to produce fermentation products, solvents and starch blends in 2013 was 2 million tonnes. This compares with annual use of 16.4 million tonnes of crystallised sugar for food applications, 7.8 million tonnes used in the production of ethanol and 1.5 million tonnes used in paper products. The domestic (EU) supply of starch crops was estimated at 329 million tonnes in 2013, of which 299 million tonnes were used in the production of food and feed and 22 million tonnes for starch production, to supply numerous non-food and non-feed industries.

Bio-TIC project estimated that 1.2 million tonnes of plant oils were used in the production of biobased materials in the EU in 2013, including 0.5 million tonnes in paints and coatings, 0.4 million tonnes for surfactants, 0.15 million tonnes for lubricants and 0.1 million tonnes for polymer production. This compares to 10 million tonnes of plant

[23] Agricultural biomass includes straw, stubbles, woody pruning & orchards residues, grassland cuttings not used for feed purposes, biomass from road side verges, by-products and residues from food and fruit processing industry.
[24] “The EU bio-based industry: Results from a survey” (JRC, 2016) https://biobs.jrc.ec.europa.eu/sites/default/files/generated/files/documents/eu-bio-based-industry-survey.pdf
[25] http://www.industrialbiotech-europe.eu/

oils used in the production of biofuels, and 13.6 million tonnes in food and feed applications.

The annual consumption of **agriculture-based lignocellulosic biomass** for non-food and feed uses is currently quite small and estimated at 15 million tonnes (dry) although information relies on individual studies that are not harmonised across EU.

### Forest biomass[26]

**Approximately 490 million tonnes of forest biomass (dry mass) are currently exploited annually in Europe (including pulp, paper and other traditional uses). S2Biom estimates that 510 million tonnes per year will be available by 2030 under sustainable practices. It is worth noting that almost one third of currently exploited forest biomass comprises of wood fuel which is frequently used in inefficient systems with inappropriate seasoning and high levels of moisture. Significant savings can be expected through the uptake of modern technologies and increased conversion efficiencies.**

**S2Biom model -based projections show that a total of 272 million tonnes forest based lignocellulosic biomass will be uptaken annually by 2030 for use as energy, fuels and innovative bio-based products and materials (excluding pulp, paper and other traditional uses).**

A recent study shows that the forest, pulp and paper industries account for a turnover of about 350 billion € and nearly 2 million jobs[27]. Over 90% of the raw wood processed into materials and products each year by the EU's forest-based industries comes from EU forests. The remaining raw wood comes mostly from Russia, North America and tropical countries.

Current use[28] of wood from European forests is estimated at 490 million tonnes per year (out of which 465 million tonnes in EU and the remainder in W. Balkans, Moldova and Ukraine). An estimated 241 million tonnes (225 million tonnes in EU) of wood used as a "classical" bio-based material primarily used in the woodworking and pulp and paper industries. 249 million tonnes (with 230 million tonnes in EU) of wood are used for production of energy (primarily heat and power).

[26] Forest biomass includes i) primary forestry production from thinnings & final fellings, stem and crown biomass from early thinnings, ii) logging residues and stumps from final fellings, iii) secondary residues from wood industries (sawmill and other wood processing).
[27] http://biconsortium.eu/sites/biconsortium.eu/files/news-image/16-03-02-Bioeconomy-in-figures.pdf
[28] Sources: EuropaBio, Nova Institut, DG ENER, Energy Community

Nowadays, demand for wood is increasing, not only from the traditional forest -based industries themselves but also from the rapidly growing bio-energy and innovative bio-based products sectors.

However, it is worth noting that annual wood harvest to date accounts for approximately 60% of net annual increment (NAI) (i.e. growth) of European forests. Recent studies, considered that annual harvest can be increased to 85 % of NAI without negative environmental impacts. Although this provides a potential resource for bio-based industries, there are significant challenges to increasing forest harvest. One of them is that around 60% of EU forest (by land area) is owned by sixteen (16) million private individuals or organisations. Individual owners are both numerous and they are increasingly urban-based, and often unaware, disinterested or unmotivated to undertake forest management. Thus, significantly enhanced efforts will be needed to engage with private forest owners and build capacity among them towards sustainable use of forests for the bioeconomy.

### Biowastes [29]

**Approximately 60 million tonnes of biowastes are currently exploited annually in Europe while 89 million per year will be available by 2030.**

**S2Biom model based projections show that a total of 81 million tonnes biowastes will be uptaken per year by 2030 to cover the demand for energy, fuels and biobased materials sectors.**

S2Biom estimates that the annual availability of biowaste amounts to a total of 89 million tonnes.

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).

Biowaste is part of biodegradable municipal waste as defined in the landfill Directive (99/31/EC), but it excludes textile and separately collected paper and paperboard. Biowaste can be separately collected or be part of integrally collected municipal waste. Separately collected biowaste can be used to generate energy by anaerobic digestion followed by composting of residues. Integrally collected biowaste can be incinerated with energy generation as a beneficial co-product, or part of the biowaste can be separated as part of “refuse-derived fuel” and subsequently combusted in a bioenergy plant.

[29] 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).

The choice for separate or integral collection of biowaste strongly depends upon the waste policy of the country in question.

## The Vision: 1 billion tonnes of lignocellulosic biomass to 2030

Recent studies and work in S2Biom provide robust scientific evidence that at least 1 billion tonnes of lignocellulosic biomass will exist in Europe on an annual basis across the various supply sectors (agriculture, forestry, biowastes and dedicated perennial crops). Part of it is now exploited by respective industries as explained in the sections above and below but there is still a lot of 'room for improvements' in efficiencies across all value chains.

The recently published studies of biomass assessments for 2020-2030 identify four primary sources that could provide additional biomass and support growth of bio-based industries, namely: agricultural residues, forest biomass, wastes and non-food crops. Additionally, they provide a range of estimates for biomass quantities for EU and neighbouring countries (Western Balkans, Ukraine, Moldova and Turkey). S2Biom research supports the evidence from previous studies by undertaking a consistent assessment for fifty (50) lignocellulosic biomass types across thirty seven (37) countries in Europe. The results are presented in the sections below together with the other studies findings.

The overall figures for all four categories across the various studies range from 1,090 to 1,420 million tonnes of biomass per year which can be available based upon current technology within Europe by 2030, under sustainable production and utilisation practices.

**The recent S2Biom estimates for the 2030 base potential (which includes the sustainability criteria as stated within the Renewable Energy Directive I) amount to 1,093 million tonnes of dry lignocellulosic biomass per year.**

Figure 2 provides a consolidated picture for the estimated ranges compared with the current uses of biomass and Map 1 shows the respective geographical distribution in regions.

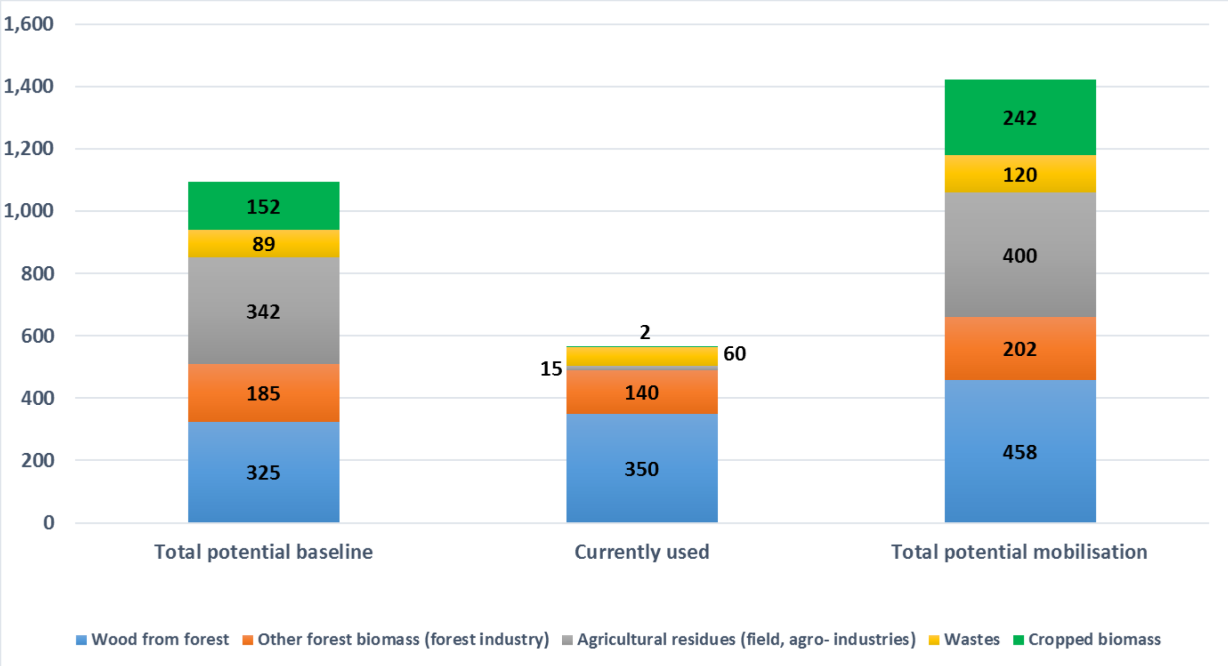
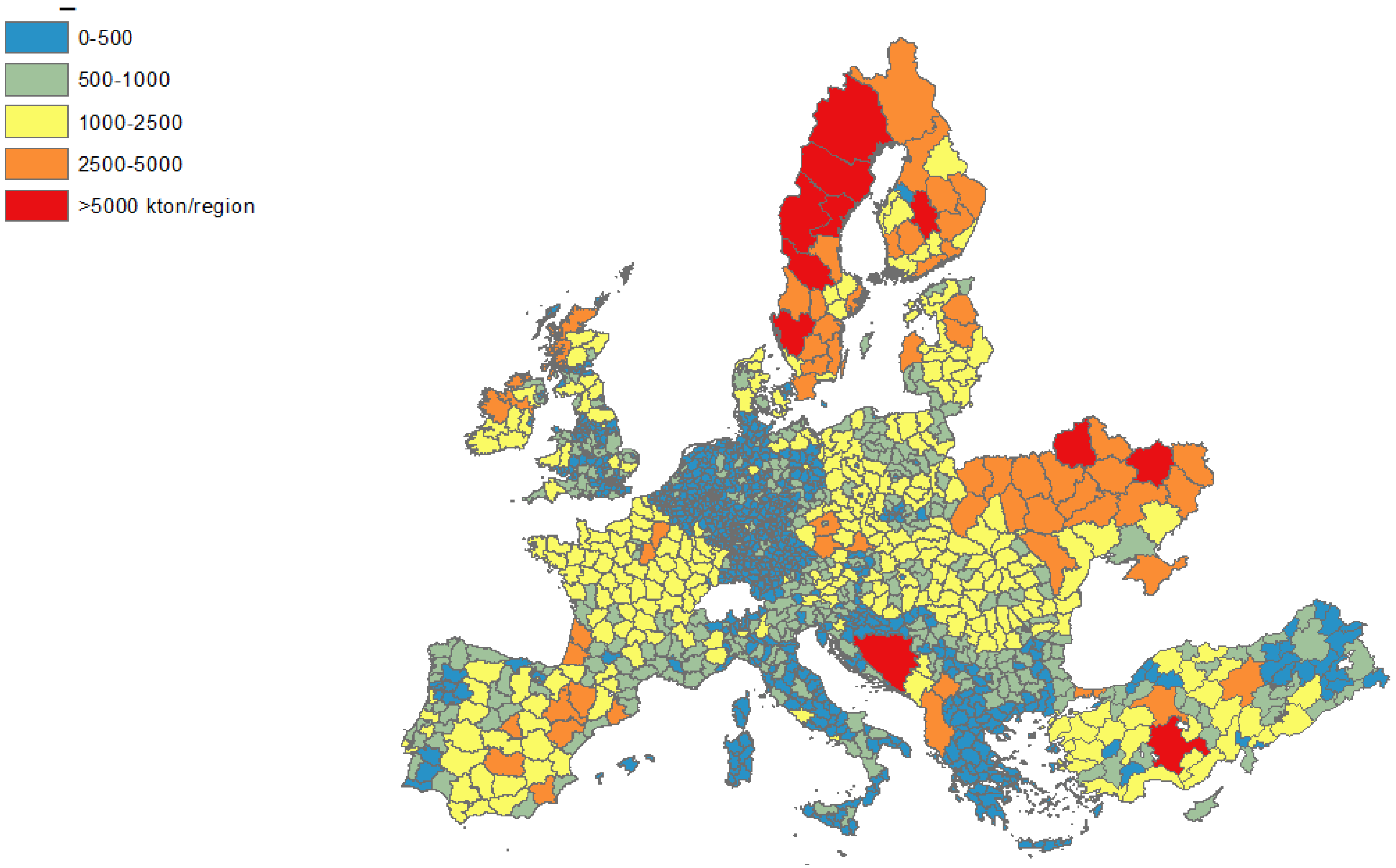



**Figure 2 Total lignocellulosic biomass potential (,000 dry tonnes per year)**




**Map 1 Total lignocellulosic biomass potential in regions (,000 dry tonnes per year)**

## Agricultural biomass[30]

Agricultural biomass provides a significant proportion of the overall European biomass potentials. This has been reported by numerous studies and has been confirmed from the recent findings of the S2Biom project.

Estimates of agricultural biomass range from 342-400 million tonnes per year by 2030. The lower estimates are based upon any need to restrict removal of residues for environmental or other reasons, for example, maintenance of soil fertility, etc.

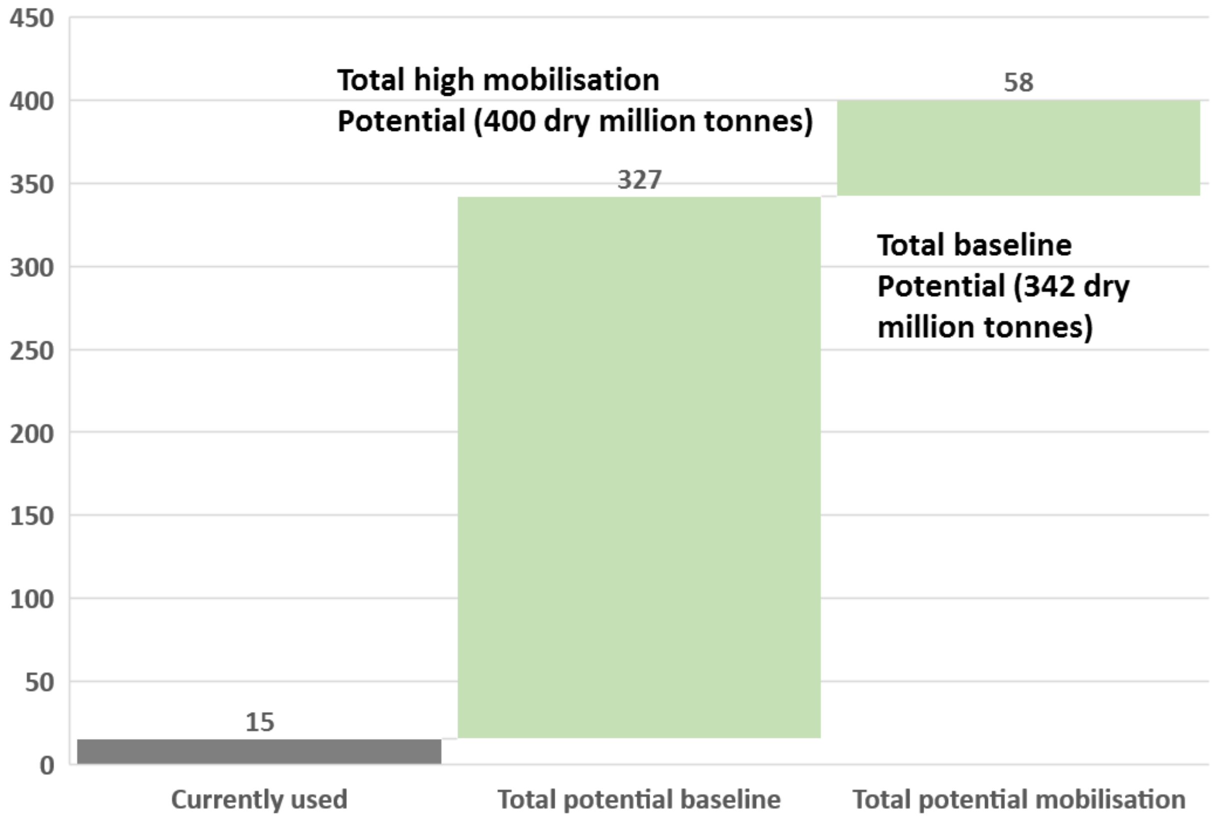
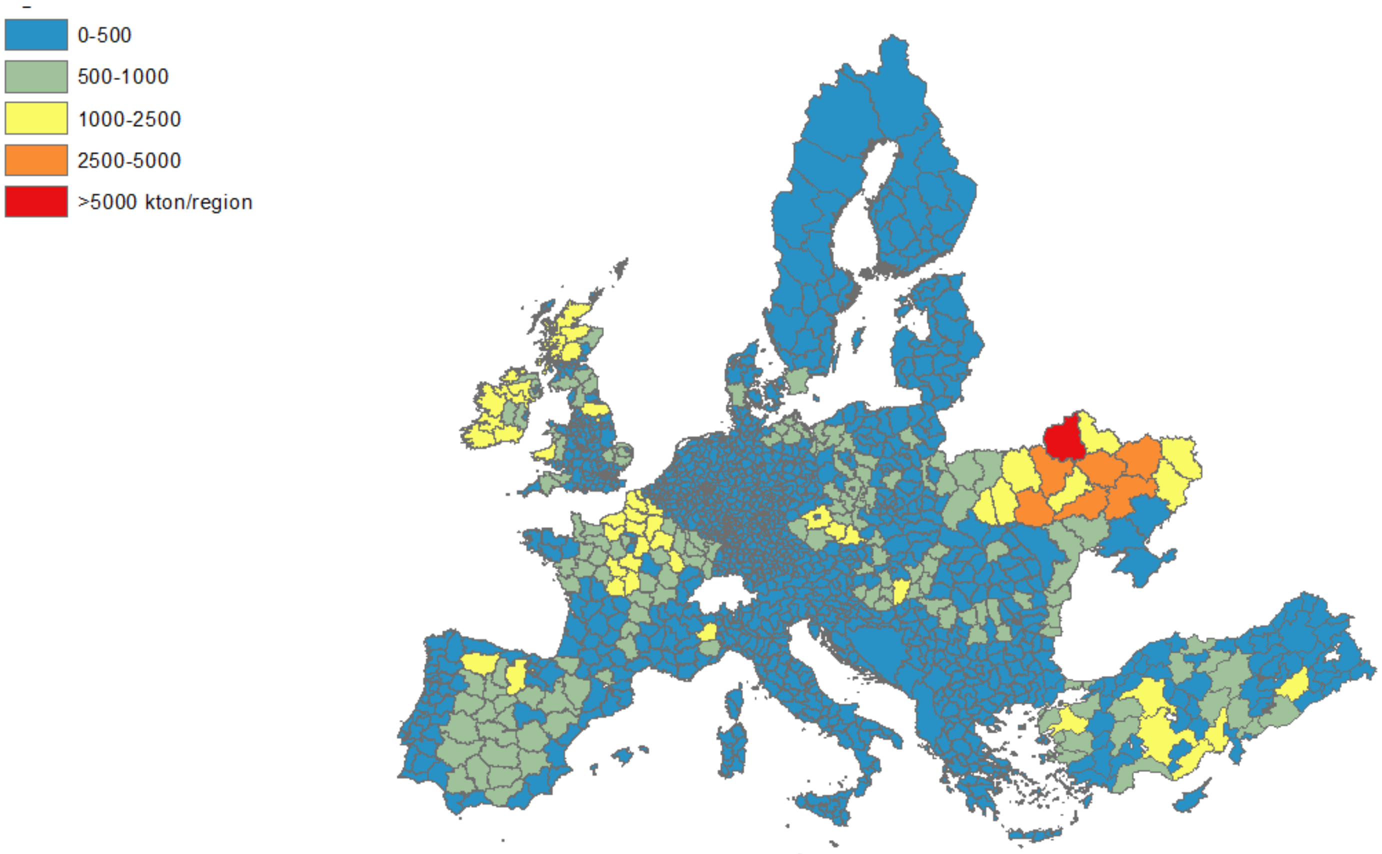



Figure 3 Agricultural biomass potentials (,000 dry tonnes per year)

However, despite the estimated potentials being high, straw and other agricultural residues use for energy purposes and innovative biobased products and materials remains low in Europe (with current use primarily to satisfy local heat demand).

The following map shows the geographic distribution of agricultural biomass in the regions covered by S2Biom.

[30] Agricultural biomass includes straw, stubbles, woody pruning & orchards residues, grassland cuttings not used for feed purposes, biomass from road side verges, by-products and residues from food and fruit processing industry.




**Map 2 Total potential of agricultural lignocellulosic biomass in regions (,000 dry tonnes per year)**

## Forest biomass[31]

Forest biomass is the most common form of biomass used in Europe so far. Estimates of available biomass range from 510 - 660 million tonnes per year by 2030. The lower estimates put strong restrictions on collection of forest residues.

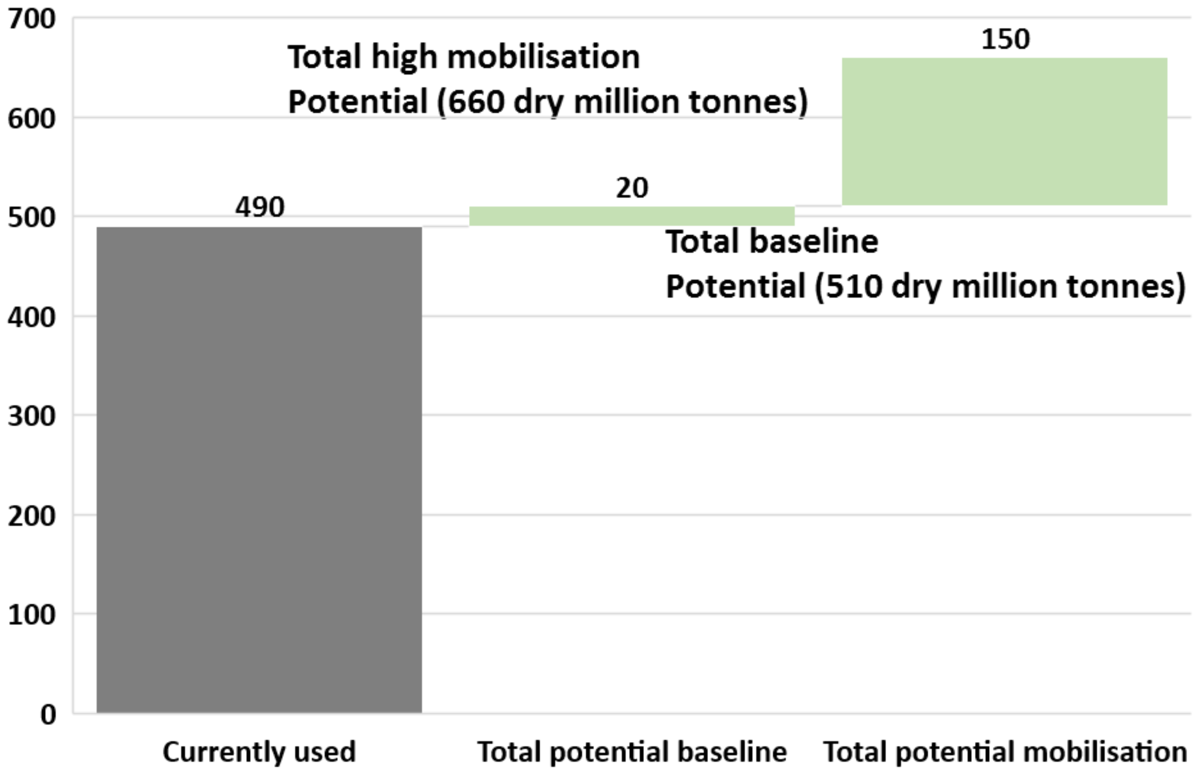



Figure 4 Forest biomass potentials (,000 dry tonnes per year)

It is important to note that not all forest ecosystems are the same in Europe and there is significant variability in current management practices across countries. Future efforts to stimulate improved use of forest biomass should be focused upon adoption of best practise to local conditions.

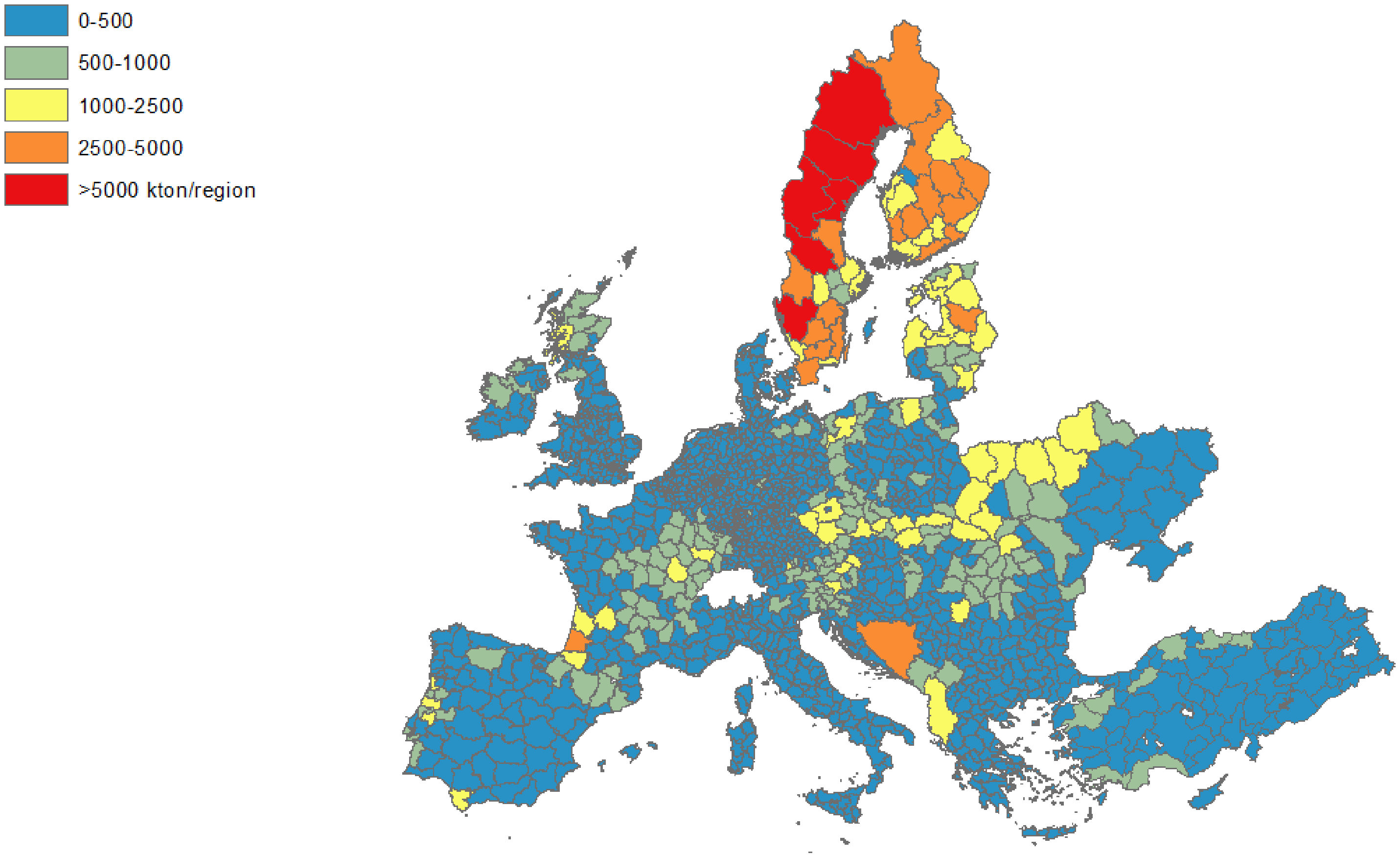
Future strategies and incentives can be considered by clustering countries that face similar challenges (e.g. storm prone areas: bring down stock; drained peat areas: reduce drainage; high stocked area: bring down stock and combine with innovation in

[31] Forest biomass includes i) primary forestry production from thinnings & final fellings, stem and crown biomass from early thinnings, ii) logging residues and stumps from final fellings, iii) secondary residues from wood industries (sawmill and other wood processing).

products; outgrown coppice: regenerate, stimulate local biomass innovation and plant adapted species.[32])

The following map shows the geographic distribution of forest biomass in the regions covered by S2Biom.

[32] European Forest Institute




**Map 3 Total potential of forest lignocellulosic biomass in regions (,000 dry tonnes per year)**

## Biowastes[33]

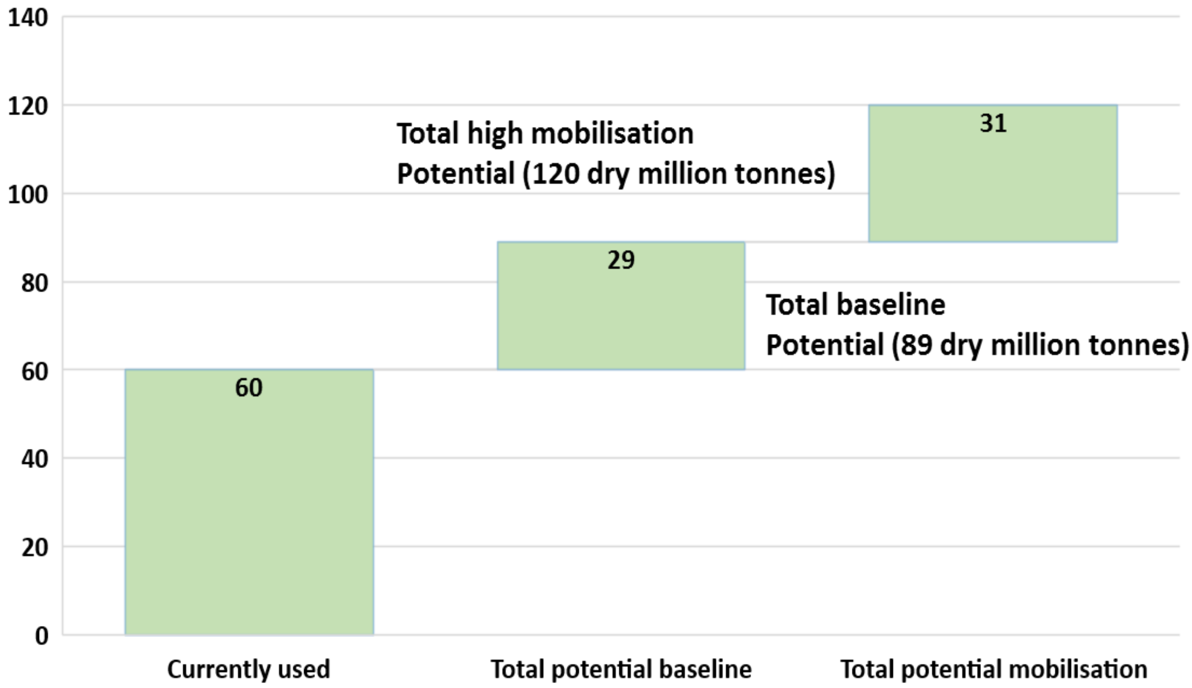


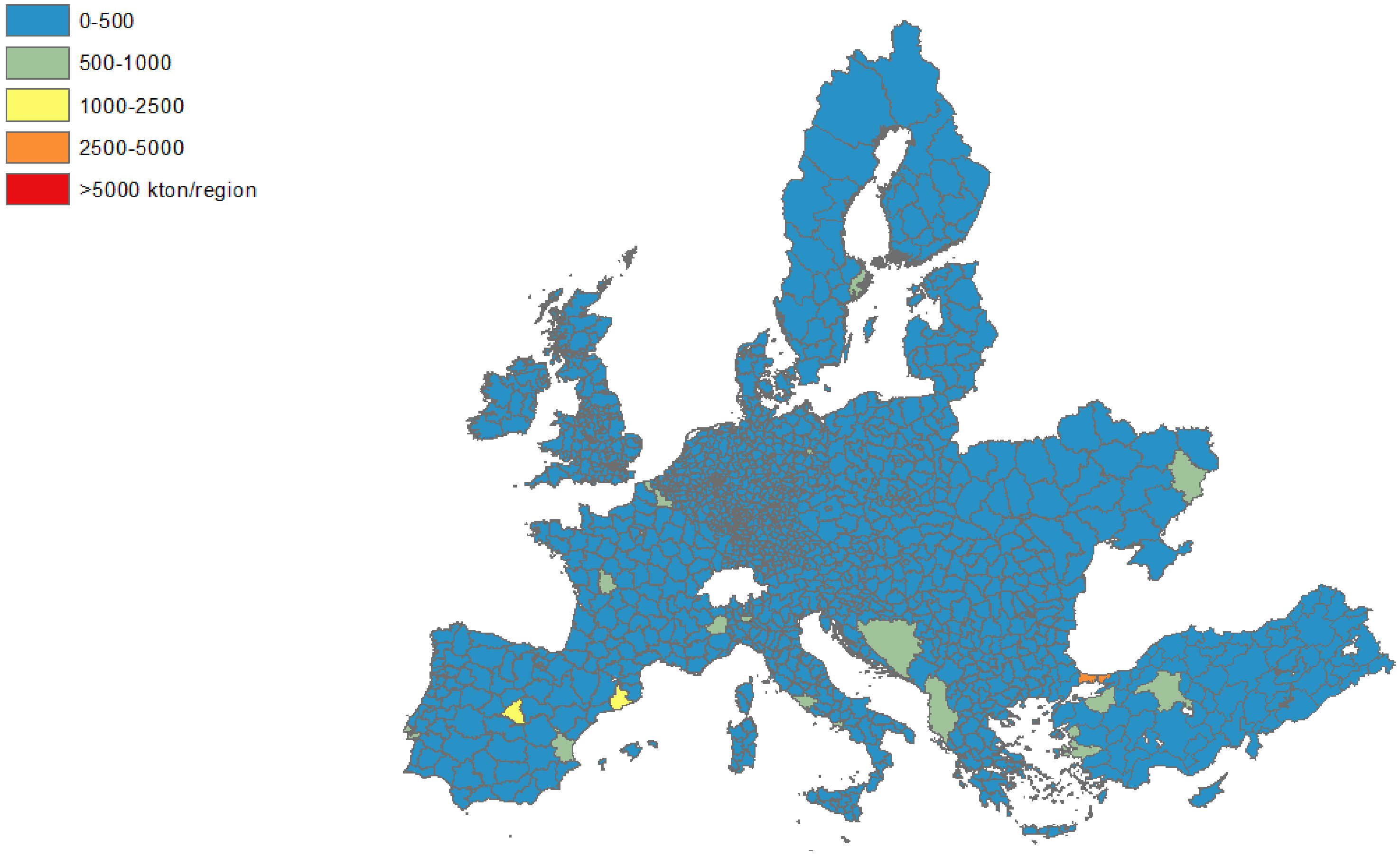

Figure 5 Waste potentials (,000 dry tonnes per year)

The higher estimates include the lignocellulosic fraction after recovery and recycling and includes paper waste, the wood fraction of Municipal Solid Waste, cellulosic material in the form of unused food and garden waste, and similar materials. It is mainly derived from households and businesses with previous estimates in the range of 89-120 million tonnes per year in Europe for 2030.

S2Biom has estimated the biowaste potentials, based upon terminology used in the Waste Framework Directive, which excludes paper waste and will amount to 89 million tonnes per year in Europe by 2030.

The following map shows the geographic distribution of biowastes in the regions covered by S2Biom.

[33] 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).




**Map 4 Total potential of biowastes in regions (,000 dry tonnes per year)**

## Land for production of dedicated non-food lignocellulosic crops

An additional source of lignocellulosic biomass relates to dedicated production of non-food crops on unused land. This issue is expected to be a major focus of further research since there are multiple factors affecting availability of additional land. These relate not only to sustainability, but also to market forces and economic profitability of traditional cropping systems in different countries. Therefore, working towards defining the potential of cropped biomass in such categories of land will remain a key issue for short to medium term investigation.

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 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.

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.

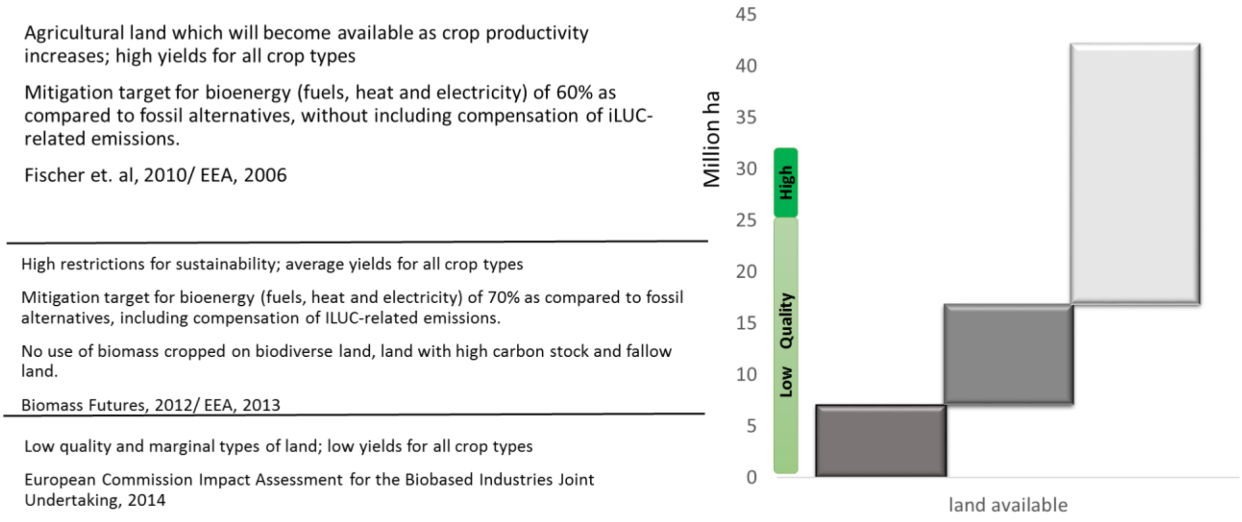



**Figure 6 Land availability (million ha) for dedicated non-food lignocellulosic crops in Europe (in green the estimates from S2Biom for availability of low and high quality land available by 2030)**

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.

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.

## Making the Vision a reality

### Improve knowledge and access to available information for biomass resources

To ensure efficient market development for the future lignocellulosic based bioeconomy, the establishment of efficient, cost-effective supply chains, providing raw materials of known and consistent quality will be essential[34].

To date, most work on availability and supply of lignocellulosic biomass has been driven by the high demand of both political and industrial actors in the bioenergy and biofuels sectors.

As such, the key assumptions used for the estimation of available biomass quantities and the respective units in which they have been expressed are strongly related to energy.

As the biobased economy evolves to cover a wider range of markets and final products it is important that future work carefully examines the synergies, conflicts and interdependencies among the different feedstocks and that coherent indicators appropriate for wide audiences are developed.

The issue of biomass availability for biobased industries is framed by a set of different bio-physical and market/ institutional key issues. Table 1 below outlines them.

**Table 1 Key issues affecting biomass availability for the future biobased industries**

| Bio- physical | Market/ institutional |
|---|---|
| • Competing uses of land, by-products and waste.<br>• Limited access to scarce resources (e.g. land, water).<br>• Logistics and economies of scale (efficient collection, processing and transport of bulky biomass feedstocks).<br>• Efficiency of agricultural & forestry practices: optimised water management, cropping strategies, harvest intervals, etc. | • Interdependencies with food and feed markets.<br>• Institutional and legislative constraints<br>• Limited access to investment capital and support.<br>• Limited interest of farmers and other land managers to make a shift towards. biomass production/harvesting systems.<br>• Lack of collaboration between land managers, entrepreneurs and local policy makers. |

[34] Europabio: Building a Bio-based Economy for Europe in 2020

Work in S2Biom project has developed and applied a harmonised approach to assess biomass availability in Europe for 2020 and 2030.

The assessment includes fifty (50) biomass feedstock types from agriculture, forestry, biowastes and dedicated perennial crops, classified and assessed with the same methodologies for thirty seven (37) European countries at NUTS3 level of geographic disaggregation.

S2Biom has concluded that future work on biomass resources should focus upon:

Knowledge

- Development of a **common set of definitions and indicators** for product to residue ratios depending on climate, ecology and feedstock related features.
- Improvement of data on local feedstock, logistics and infrastructure, **employing bottom up methodologies** to ensure that stakeholders (government, trade associations, producer groups, users) can target efforts on regions with high biomass occurrence.
- **Knowledge for yield improvements**, particularly on closing the yield gap in conventional crops to produce more of the main product and of residues per hectare of land. This will help to bring down unfavourable indirect land use change (ILUC) effects elsewhere in the world and increase the domestic availability of biomass for the bioeconomy.
- **Knowledge for new cropping systems** such as inter-row cropping, or double cropping to increase sustainable intensification of existing agricultural land to produce more biomass per hectare.
- Develop **better understanding of the biomass composition** and develop biorefinery technologies and logistics in a way that full deployment of feedstocks takes place without creating unused waste streams, thereby adding as much value as possible.

Capacity building

- **Knowledge and information** should be **tailored** and be **readily digested for the actual end user**.
- **Education and support to land managers** to widen their practices for both main product and residues production.

Communication

- **Guidelines** with simplified methodological steps **for local practitioners** will be a particularly helpful tool.
- **Improve knowledge transfer** among biomass producers and users of biomass.

**Table 2 Future research for improved knowledge and access to information for biomass resources**

| Knowledge | Capacity building | Communication |
|---|---|---|
| Develop common set of definitions and indicators.<br>Employ bottom up methodologies.<br>Develop knowledge for yield improvements and new cropping systems.<br>Improve understanding of the biomass composition. | Tailored knowledge and information.<br>Education and support to land managers. | Guidelines for local practitioners.<br>Improved knowledge transfer among biomass producers and users. |

## Reduce costs across the value chain

Feedstock costs are the greatest contributor to production costs in most conversion pathways. Taking into consideration the current costs of wood and agriculture residues, the feedstock cost share is 40%-70% of total production costs.

Establishing practical, efficient feedstock supply chains at scale, therefore, is crucial for the future success of bio-based economy.

**Cost reduction** is considered essential to facilitate increased mobilisation of the resource base. A wide range of lignocellulosic feedstocks can be found in Europe varying in concentration and production practices. Their costs and prices are also subject to different market dynamics from food/ feed to fossil fuels. Agricultural residues have major potential which remains largely unexploited (with exceptions e.g. straw for feed) because of lack of organised infrastructures and knowledge within farming communities in many European countries. Forest residues are used extensively in energy and some non- energy innovative bio-based applications but further cost reductions are both needed and possible by improving logistics and storage infrastructure, especially for countries in south east and eastern Europe. Dedicated crops can be produced with adequate cost efficiency with improved practices and yields in available land.

**Innovation** can reduce cost of biomass supply and logistics, and improve the conversion yield to useful biobased products and materials.

Along with technological innovation, **policies and business models** are needed to ensure mobilisation and security of supply both in terms of quantities and quality while production costs are optimised both for producers and the industry.

**Logistics** is a key parameter for the cost-efficient implementation of biorefineries. The efficiency at which lignocellulosic biomass feedstock can be used for producing biobased services is very important. In this respect biomass feedstocks pose a significant logistical challenge as the quality and handling characteristics, and often also moisture content of biomass often restricts the available options for efficient logistics and of efficient conversion into bio-energy, biofuels, biochemicals or biobased products. The various factors that affect biomass feedstock quality for thermal and biochemical conversion need to be optimised through the optimal design of sustainable biomass feedstock supply chains. The integration of new logistical concepts (e.g. storage and pre-treatment at intermediate biomass hubs) together with emerging near-farm pre-processing and densification technologies (e.g. pelletisation to produce bio-commodities) in an optimisation framework will facilitate the identification and further implementation of new logistics systems.

S2Biom has concluded that future work on biomass resources should focus upon:

Knowledge

- **Improved information on production costs** so that research and development can be targeted to reduce costs and improve value chain financial viability.
- **Develop rural infrastructures** and **engage with producer groups, storage facilities and transport experts** to facilitate year- round supply and address key elements in the supply chain such as specially modified or designed vehicles.
- **Improve access to finance** to improve costs, secure contracts with users, etc. There is a need for low cost finance (grants, loans, insurance schemes) to underwrite risk for investors in biomass supply. Support may also be provided to help reduce the transaction costs associated with creating new supplies, for example providing standard forms of contracts as they already exist with other agricultural crops (between an aggregator and individual producers; between the user and aggregator, etc.).

Capacity building

- **Train biomass traders** to assist in extending their businesses.
- Work with entrepreneurs to **create new business models**.
- **Transfer knowledge** and **learn from Good Practices** from countries with increased experience such as Austria, Finland, etc.

Communication

- Targeted **campaigns to raise awareness** of the opportunities for potential feedstock producers.
- **Develop standard specifications** for feedstocks, biomass fuels and biobased products. Standards are an important tool to overcome the challenge of variable quality that arises because of the diverse range of lignocellulosic feedstock types.

**Table 3 Future research for reduced costs across the value chain**

| Knowledge | Capacity building | Communication |
|---|---|---|
| Improve information on production costs.<br>Develop rural infrastructures and engage with producer groups, storage facilities and transport experts.<br>Improve access to finance. | Train biomass traders.<br>Develop standard specifications.<br>Transfer knowledge and learn from Good Practices. | Organise campaigns to raise awareness.<br>Develop standard specifications. |

## Support technological innovation

Opportunities for innovation exist across the entire spectrum of conversion pathways. Significant improvements to all of them are expected to come from process integration and further developments in biorefineries.

## Heat & Electricity

The production of heat and electricity from lignocellulosic biomass has reached technical maturity. Various technologies have been implemented across Europe, both at a large (centralised) scale and at a small (decentralised) scale.

In the field of **combustion**, typical technologies are grate combustors and fluidised bed combustors. Most of them operate with wood (typically forest or industrial residues) as feedstock, but also straw combustion is a common technology in some EU countries. The main opportunities for innovation exist in the use of “lower-quality” biomass, such as agricultural residues, grass, leaves, to produce heat and/or electricity.

**Gasification** of biomass to produce heat and electricity is a technology that has been proven to work on a very small scale (<1MW), and is used at very large scale (>100 MW, biomass co-firing with coal), but the intermediate scale has not been applied widely. Several demonstration plants exist, such as the ones of Güssing in Austria and GoBiGas in Sweden, but commercial operation still faces challenges.

**Fast pyrolysis** of biomass for heat and electricity is reaching commercial maturity. Currently there are three commercial pyrolysis plants in operation worldwide, of which two are in Europe (in Finland and the Netherlands). The produced pyrolysis oil is being applied to produce heat and/or electricity. Most efforts in further development of pyrolysis technology (besides large-scale role to produce heat and electricity) focus on the production of advanced biofuels and biochemicals.

The commercial maturity and market introduction of **torrefaction technologies** has gone slower than anticipated. Important challenges to date relate to improving quality of final products and durability compared to conventionally produced wood pellets.

## Advanced biofuels

Whilst there are several advanced biofuel conversion technologies, their technological maturity is at different stages[35].

**Hydrolysis and fermentation** to produce ethanol from lignocellulosic biomass has almost reached commercial maturity, with several first-of-its-kind plants in the start-up or early operation phase, such as the one of Biochemtex in Italy and the ones of POET-

[35] IRENA, 2016. Innovation Outlook: Advanced Liquid Biofuels.http://www.irena.org/menu/index.aspx?mnu=Subcat&PriMenuID=36&CatID=141&SubcatID=2741

DSM and Du Pont in the USA. In the future, these processes could be greatly reduced in cost by integrating the two steps to reduce enzyme loading, modifying fermentation organisms and applying membrane separation. In the ButaNexT project, Green Biologics is scaling up its fermentation process and integrating the *in-situ* removal of butanol with a membrane separation process developed by VITO (ButaNexT, 2016).

**Fast Pyrolysis** is highly efficient and, potentially, has low processing costs. Currently there are three companies that operate commercial fast pyrolysis plants, namely Ensyn (USA), Fortum (Finland) and BTG-BTL (The Netherlands). More effective catalytic upgrading processes are needed to produce advanced biofuels from pyrolysis oil. Petrobras and Ensyn have demonstrated that co-processing pyrolysis oil production in the fluid catalytic cracking process of a conventional refinery is possible, yielding bio-based gasoline, kerosene, and diesel.

**Gasification** is possible with a range of feedstocks. Many pilot and demonstration projects exist, but few commercial plants have been built yet. Enerkem has built the first commercial plant to convert municipal solid waste to methanol in Canada. Gasification technology needs to prove reliable long-term operation in view of feedstock contaminants. Alter-NRG is working on enhanced pre-treatment and ash removal using plasma gasification or plasma torches. Process optimisation is also needed to achieve target syngas composition.

**Fischer-Tropsch processes** need to be proved at commercial scale for biomass use. Velocys is one of the companies developing modular units, which may enable reactors to operate at smaller scales to match local feedstock supplies.

**Alcohol fermentation from syngas** could benefit from modification of fermentation organisms to improve tolerance to contaminants, raise yields and boost selectivity.

### Bio-based chemicals & plastics

The field of bio-based chemicals and plastics is under rapid development. Various bio-based chemicals and polymers are already available in commercial quantities. Most of these are based upon traditional bio-based feedstocks such as starch, sugars or plant oils. Therefore, these were not taken into consideration in the S2Biom project. The expectation however is that by 2030 many of the processes that were described above and are currently under development for advanced biofuels, will also be able to yield chemical products in commercial quantities by 2030. Examples of these technologies are gasification (the syngas platform), fast pyrolysis, and especially also the sugar platform, in which fermentation technologies will play an important role to convert lignocellulosic (C5 and C6) sugars simultaneously to other products and intermediates than ethanol.

Future actions should investigate the scope for using novel biomass. Evidence suggest that more and more wastes and residues can be used as feedstock to produce chemicals and polymers; This is favoured as these routes do not compete with food production or land use. However novel and efficient technologies need to be developed to deal with the inherent variability of waste and residue products.

S2Biom has concluded that future work on biomass resources should focus upon:

Knowledge

- The field of biomass conversion technologies is a dynamic one, with constant changes and many new developments. **Knowledge in terms of efficiency and relevant metrics across value chains** should be under continuous development.
- The optimisation of conversion and technologies could lower costs and improve efficiency of production (more can be produced with the same amount of feedstock). There is a need to ensure continuous improvement of technologies, so future efforts for research and innovation on such issues should be prioritised.

Capacity building

- **Educate stakeholders** in the bioeconomy on what is already possible with biomass technologies and what will become possible in the years to come.

Communication

- Customers and end users are not necessarily aware of environmental and social benefits that biobased chemicals and plastics can offer. **Information campaigns to customers and end-users** can help develop the market. Brand owners will play a crucial role within this process.

**Table 4 Future research for supporting technological innovation**

| Knowledge | Capacity building | Communication |
|---|---|---|
| Develop knowledge for efficiency and relevant metrics across value chains.<br>Focus technological innovation on process optimisation to produce advanced biofuels and chemicals. | Educate stakeholders for the advance technologies and the actual benefits they can offer in terms of resource e efficiency, reduction of pollutants, etc. | Information campaigns to customers and end-users. |

## Improve framework conditions

### Policy

The increased use of lignocellulosic biomass offers benefits across a range of interest issues that are important to policy makers. The issues and their relative priority are always location specific but they also include some common key priorities: promotion of rural economies; nature conservation; watershed management; forest fire prevention; soil conservation; commercial and industrial development; inward investment; use of domestic renewable resources; greenhouse gas reduction.

Supporters for lignocellulosic biomass need to develop simple narratives for policy makers. These must tie together the relevant issues, describe the benefits concisely, quantify benefits in monetary terms, and show in a credible way what can be achieved by potential policy interventions.

A priority for policy makers is to create long term certainty for potential investors. This requires policy makers to set realistic short, medium and longer term objectives – including quantified targets – for increased use of lignocellulosic biomass within their jurisdictions. There must be a clearly defined roadmap of how these objectives are to be accomplished and this should be supported through well considered and financeable support mechanisms.

If this policy package has wide political support, is financeable, and demonstrated to be succeeding, confidence will be created among investors that there is certainty in going forward for the bio-based economy.

### Financing

Grants to perform scaling up of pilot plants and financing for demonstration activities are required to test and evaluate technical concepts and claims. Loan guarantees and other risk management tools can be an efficient way to stimulate private debt funding for such projects, up to commercial scale. They allow governments to reduce the credit risk to financial institutions lending to projects focusing on biobased products and advanced biofuels.

Internalising carbon costs in the market will encourage quicker lignocellulosic feedstock mobilisation.

Strategic partnerships and joint ventures allow companies to share expertise and financial risk and should be considered.

Effective business models coupling agriculture, forestry and waste sectors with the energy, fuels, biochemicals and plastics will raise awareness for potential opportunities. This will also ensure a fair price for feedstocks, the development of infrastructure for collection, storage and transportation of biomass as well as guaranteed supply at a foreseeable prices.

## Sustainability

The focus should be upon sustainable intensification options. This covers three pillars:

1) Yield improvements in conventional (food and feed) crops and in forests which are currently not or under managed. In particular, it requires the stimulation and facilitation of the yield gap closure in agricultural crops. Many regions in Europe still have very low yield far below their attainable yield levels. Closing this gap will increase productivity strongly and will lower the demand for imports of food, feed and biomass from outside the EU. It will therefore bring down indirect effects of land and water use elsewhere in the world.
2) Yield improvements through introduction of new and improved land management and harvest systems both in forest and agriculture.
3) Bringing into use of unused land and forestry resources whilst combining this with careful monitoring of effects of ecosystem services.

S2Biom has concluded that future work on biomass resources should focus upon:

Knowledge

- **Improve policy narratives** and set clear visions.
- **Develop** clear and **specific roadmaps** with concrete steps and impact quantification.
- **Understand the local context** under which the measures would be best suited and adapt to local needs and infrastructures.

Capacity building

- **Build 'trust'** among research, policy and industry.
- **Improve information provision measures** with special focus on farmers; foresters; local authorities and waste management related stakeholders. Information must be readily comprehensible at the operator/manager level.

Communication

- **Communicate simple and clear messages** to the public / consumers about the importance of policies and the benefits their implementation can bring to everyday life.
- **Discuss future policy recommendations with local communities** and jointly tailor them to face new opportunities and challenges.
- **Ensure** wide acceptance and **endorsement by local stakeholders**.

**Table 5 Future research to improve framework conditions**

| Knowledge | Capacity building | Communication |
|---|---|---|
| Improve policy narratives.<br>Develop specific roadmaps.<br>Understand the local context. | Build ‘trust’ among research, policy and industry.<br>Improve information provision measures. | Communicate simple and clear messages.<br>Discuss future policy recommendations with local communities.<br>Ensure endorsement by local stakeholders. |

## Concluding remarks

Efforts to develop the lignocellulosic biobased economy in Europe are strong and political will is confirmed while both research and industrial efforts are intensified.

Ongoing R&D and industrial development plus increased drivers to use renewable raw materials have seen the focus widening for energy and fuels to include value chains for bio-based chemicals, pharmaceuticals and other materials.

Consequently, policy, industry and regional stakeholders in Europe are now exploring increasingly varied configurations of value chains with the aims of mobilising regional biomass sources sustainably, generating financial returns and achieving high quality products for consumers.

S2Biom improved scientific evidence for the sustainable biomass potentials of non-food biomass at local, national, macro-regional and pan-European level. This has been achieved through developing a “computerized, easy to use” planning toolset (and respective open access databases) with up to date harmonized data for EU, western Balkans, Moldova, Ukraine and Turkey. The spatial level of analysis both for the toolset and the databases includes NUTS1 (country), NUTS2 (regional) and NUTS3 (local level).[36]

The toolset has also been used within the project duration to inform the Vision presented in this report, a set of strategies and Roadmaps and illustrate how the evidence generated by the project can offer valuable information to both policy makers and industrial actors.

Future actions towards mobilisation of lignocellulosic biomass in European regions should not only target techno- economic availability and sustainability but also policy formation. This refers to the need for harmonised regulations, tailored financing for innovative value chains as well as information provision to authorities, farmers/foresters and other actors in the supply chain at regional level.

[36] See: http://en.wikipedia.org/wiki/Nomenclature_of_Territorial_Units_for_Statistics