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

S2Biom Project Grant Agreement n°608622

D1.6

A spatial data base on sustainable biomass cost-supply of lignocellulosic biomass in Europe - methods & data sources.

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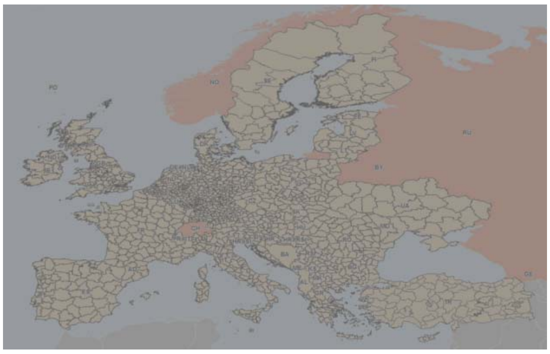

About S2Biom project

The S2Biom project - Delivery of sustainable supply of non-food biomass to support a "resource-efficient" Bioeconomy in Europe - supports 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 "computerized and easy to use" toolset (and respective databases) with updated harmonized datasets at local, regional, national and pan European level for EU28, Western Balkans, Moldova, 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

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List of Acronyms and Abbreviations

AEROGRID	AeroGRID, is a new partnership that delivers high-resolution aerial photography from across Europe and beyond. For more information see: https://www2.getmapping.com/m/Products/AeroGRID
ABC	Activity Based Costing
BACI	BACI is the World trade database. See glossary of models
BEE	Biomass Energy Europe, an FP7 project
BISO	Bioeconomy Information System Observatory
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regionalised Impact See glossary of models
CEPI	Confederation of European Paper Industries
CHP	Combined heat and power
CLC	Corine Land Cover
COMTRADE	The United Nations Statistical Divisions International Trade statistics (COMTRADE database). UN Comtrade is a repository of official trade statistics and relevant analytical tables. It contains annual trade statistics starting from 1962 and monthly trade statistics since 2010
Copernicus	Copernicus, previously known as GMES (Global Monitoring for Environment and Security), is the European Programme for the establishment of a European capacity for Earth Observation, jointly

	established by the European Commission and the European Space Agency.
EEA	European Environment Agency
ETC/SIA	European Topic Centre on Spatial Integration and Analysis
EFISCEN	European Forest Information SCENario model See glossary of models
EFSOS	European Forest Sector Outlook Study
EPIC	EPIC (Environmental Policy Integrated Climate Model) See glossary of models
ESRI	GIS database from which data on road were used to make an estimation of road side verge grass potential. Europe Roads included cover European Highway System, national, and secondary roads.
EU	European Union
EUWood	Real potential for change in growth and use of EU forests - report
FAO	Food and Agriculture Organization of the United Nations
FADN	Farn Accountancy Data Network
FAOSTAT	Statistical service of FAO
FSS	Farm Structural Survey
FYROM	Former Yugoslavian Republic of Macedonia
G4M	G4M (Global Forest Model), see glossary of models
GAMS	General Algebraic Modelling System
GDP	Gross domestic product
GDD	Growing degree days
GIS	Geographic Information System
GLOBIOM	Global Biosphere Management Model
GWSI	Global Water Satisfaction Index
IEA	*International Energy Agency*
ILUC	Indirect land use change
HI	Harvest Index
HNV	High Nature Value
INFRES	Innovative and effective technology and logistics for forest residual biomass supply in the EU, an FP7 project
ISO	International Organization for Standardization
JRC	Joint Research Centre
LPJmL	Lund-Potsdam-Jena managed Land global vegetation model
LUCAS	Land Use and Cover Area frame Survey
LUISA	Land Use Modelling Platform developed by JRC, see glossary of models
MARS	Monitoring of Agriculture with Remote Sensing

MBT	mechanical biological treatment
MDF	*Medium-density fibreboard*
MFI	Monetary financial institution
N/A	Not applicable
NPV	Net Present Value
NUTS	Nomenclature of Territorial Units for Statistics of the European Union
NUTS0, NUTS1, NUTS2, NUTS3	NUTS, the Nomenclature of Territorial Units for Statistics of the European Union structures the territorial units hierarchical, starting with the National level (= NUTS0), followed by NUTS1 and NUTS2 and NUTS3.
NVC	Net calorific value
OSB	Oriented strandboard
PCW	Post-consumer wood
PJ	*Petajoule*
RED	Renewable Energy Directive (EC, 2009)
SFR	Secondary forest residues
SOC	Soil Organic Carbon
SRC	Short rotation coppice
USD	US Dollar
VAT	Value-added tax
WP	Work Package
WUE	Water Use Efficiency

Glossary of models

Aglink-Cosimo	Aglink-Cosimo is a recursive-dynamic, partial equilibrium model used to simulate developments of annual market balances and prices for the main agricultural commodities produced, consumed and traded worldwide. It is managed by the OECD and Food and Agriculture Organization of the United Nations (FAO), and used to generate the OECD-FAO *Agricultural Outlook* and policy scenario analysis.
AquaCrop Model	AquaCrop model is a crop water productivity model developed by the Land and Water Division of FAO. Revision on FAO Irrigation and Drainage Paper No. 33 “Yield Response to Water” (Doorenbos and Kassam, 1979)
BACI	BACI is the World trade database developed by the CEPII at a high level of product disaggregation. BACI provides the historically trade flows where the trade between countries is fully reconciled such that reported imports for country A from country B, fully match that of reported export from country B to country A.
CAPRI	Common Agricultural Policy Regionalised Impact. Global agricultural sector model with focus on EU28, Norway, Turkey and Western Balkans, iteratively linking: Supply module (EU28+Norway+Western Balkans+Turkey): covering about 280 regions (NUTS 2 level) up to ten farm types for each region (in total 2,450 farm-regional models, EU28) Market module: spatial, global multi-commodity model for agricultural products, 47 product, 77 countries in 40 trade blocks
COST model for calculation of forest operations costs	A model to calculate hourly machine costs of forest operations developed for the European Cooperation in Science and Technology (COST) Action FP0902
EFISCEN	European Forest Information SCENario model: a large-scale forest model that projects forest resource development on regional to European scale. The model is suitable for the projection of forest resource development for a period of 50 to 60 years.
EPIC	EPIC (Environmental Policy Integrated Climate Model) (Williams 1995) is an agriculture model which provides the detailed biophysical processes of water, carbon and nitrogen cycling, as well as erosion and impacts of management practices on these cycles.
G4M	G4M (Global Forest Model) is a global forest model that was developed by IIASA (Kindermann et al. 2008a; Gusti 2010) to provide estimates of availability and cost of woody biomass resources (Gusti and Kindermann 2011), and is used in conjunction with GLOBIOM to estimate the impact of forestry activities on biomass and carbon stocks.
GAINS	Greenhouse Gas – Air pollution Interactions and Synergies: The

	GAINS model explores cost-effective emission control strategies that simultaneously tackle local air quality and greenhouse gases so as to maximize. The model was developed by IIASA
GLOBIOM	Global Biosphere Management Model is a global land use model developed by IIASA (Havlik et at 2014) to analyze the competition for land use between agriculture, forestry, and bioenergy, which are the main land-based production sectors. As such, the model can provide scientists and policymakers with the means to assess, on a global basis, the rational production of food, forest fiber, and bio-fuels, all of which are vital for human welfare.
LPJmL	Lund-Potsdam-Jena managed Land global vegetation model
LUISA	Land Use Modelling Platform developed by JRC
MITERRA-Europe	Model developed for DG-ENV that calculates GHG (CO_2, CH_4 and N_2O) emissions, SOC stock changes and nitrogen emissions from agriculture on a deterministic and annual basis. It is based on the CAPRI and GAINS models, supplemented with a nitrogen leaching module, a soil carbon module and a module for representing mitigation activities
RothC	Rothamsted Carbon Model: it assesses the turnover of organic carbon in non-waterlogged topsoils taking account of the effects of soil type, temperature, moisture content and plant cover.

1 Introduction

This report accompanies the data base on cost supply potentials. The data base comprises both the sustainable supply and cost of solid lignocellulosic biomass from forestry, dedicated energy cropping, agricultural residues, and secondary residues from wood and food industry as well as from waste. Supply and cost data are provided on NUTS 3 level per single category and expressed in tonnes (dry matter or as received as specified in this report for the specific categories). In case of wood from forests and of secondary forest residues data are also supplied in cubic metres. To each category the cost at road side respectively at gate is determined in order to enable the assessment of economic potentials using the cost-supply method.

Data are provided for 2012, 2020 and 2030. They are provided for several 'potentials' including: a technical potential; a base potential considering currently applied sustainability practises; and further potential levels that are determined considering changing sustainability restrictions, mobilisation measures and different constraints to account for competing use.

This report documents the methods that have been applied to determine cost and supply per resource category. It includes a description of relevant projects, data sources and tools necessary to determine the cost-supply data.

It is structured in an introduction and chapters by major origin both for methods used to determine supply and the roadside cost.

The results are presented in the form of national level tables and in NUTS3 based maps in the report D1.8 "Atlas with regional cost supply biomass potentials". They are also made publically available via the S2BIOM online tool that allows customised analysis and download.

The objective is to provide information on cost-supply of biomass for the utilisation for energy and bio-based products, since the development of these two sectors using biomass is the focus of S2BIOM.

The term bio-based products is used following a definition given by the Taskforce on Bio-based Products (2007) and further referenced in a report on sustainability issues in the scope of the Bioeconomy Information System Observatory (BISO) (European Commission, 2013):

> *"Bio-based products are "non-food products derived from biomass (plants, algae, crops, trees, marine organisms and biological waste from households, animals and food production). Bio-based products may range from high-value added fine chemicals such as pharmaceuticals, cosmetics, food additives, etc., to high volume materials such as general bio-polymers or chemical feedstock. The concept excludes traditional bio- based products, such as pulp and paper, and wood products, and biomass as an energy source." They*

include: fibre-based materials; bio-plastics and other bio-polymers; surfactants; bio-solvents; bio-lubricants; ethanol and other chemicals and chemical building blocks; pharmaceutical products incl. vaccines; enzymes; cosmetics; etc.. "

Methods described in the BEE handbook (BEE, 2011) to determine biomass potentials for energy are used as a general reference besides further methodological references, since the approach to determine potentials for energy and those for bio-based products do not differ.

Four types of biomass potentials are commonly distinguished:

- Theoretical potential.
- Technical potential.
- Economic potential.
- Implementation potential.

The types of potentials differ with respect to the constraints that are considered including sustainability issues (Figure 1). Within S2BIOM, the focus will be on the sustainable technical potential and the sustainable economic potentials. The single constraints that are actually considered are described in this report in the section on the technical potential and are specific per biomass type.

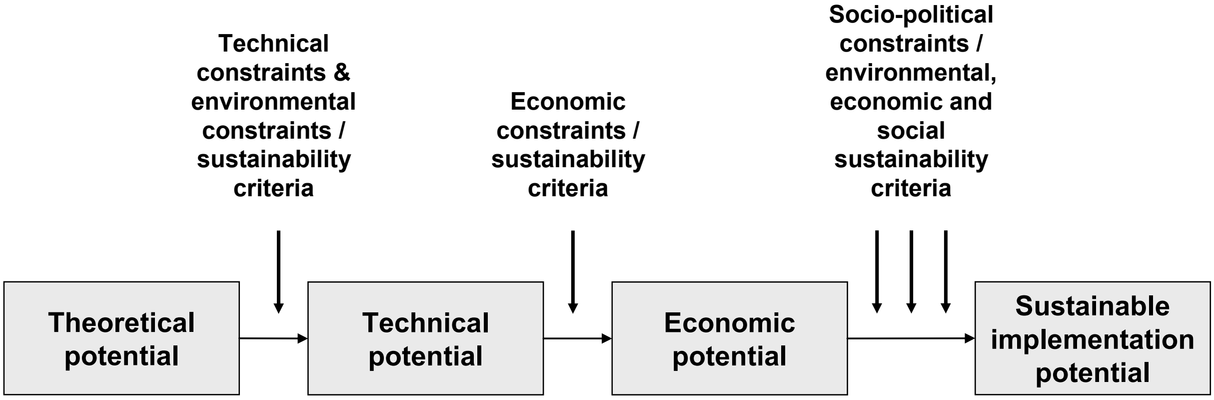


Figure 1 The integration of sustainability criteria in biomass potential assessments

Source: Vis & Dees (2011).

The different types of potentials can be determined using different types of approaches and general methodologies (Table 1) (Vis & Dees, 2011, Dees et al. 2012).

The cost supply approach selected for the S2BIOM database allows the determination of an economic potential and thus provides substantially more information compared to the majority of studies on potentials available to date.

Table 1 An overview of the combinations of approaches and methodologies that are used in the best practice handbook

General approach	General methodology	Type of biomass potential	
		Theoretical-technical biomass potentials	Economic-implementation biomass potentials
Resource-focused	Statistical methods	Yes	No
Resource-focused	Spatially explicit methods	Yes	No
Resource-focused	Cost-supply methods	No	Yes
Demand-driven	Energy-economics and energy-system model methods	No	Yes
Integrated assessment	Integrated assessment model methods	Yes	Yes[c]

The cost-supply methodology is described in the BEE Handbook with focus on biomass potentials for energetic use as follows:

> "*Cost-supply methods start with a bottom-up analysis of the bioenergy potential and costs, based on assumptions on the availability of land for energy crop production, including crop yields, forest biomass and forestry residues. The demand of land and biomass for other purposes and other environmental and technical limitations are included, ideally by scenario analysis. The resulting bioenergy cost-supply curves are combined with estimates of the costs of other energy systems or policy alternatives, often with specific attention for policy incentives (e.g. tax exemptions, carbon credits, and mandatory blending targets).*"

It should be emphasised here that the cost levels assessed in this WP1 of the S2BIOM project are limited to the road-side-cost. Costs that are encountered downstream in transport, logistics, pre-treatment and conversions to energy and other biobased (intermediate) products are covered in other reports and databases generated in S2BIOM as part of Work packages 2 (conversion technologies), 3 (logistics) and WP4 in the full chain assessment tools (Bio2Match, BeWhere and LocaGIStics tools).

Lignocellulosic biomass assessed by S2BIOM includes biomass originating from the following:

- Primary residues from agriculture
- Dedicated cropping of lignocellulos biomass on agricultural area

- Wood production and primary residues from forests
- Other land use
- Secondary residues from wood industry
- Secondary residues of industry utilising agricultural products
- Waste collection/ tertiary residues

The report is structured along these major origins. Each dedicated chapter starts with a list of categories covered that includes IDs that refer to the data base structure. Per category both methods to determine supply and cost are presented in a dedicated chapter, where the subcategories per major origin are further specified and where the methods to determine the potential supply and the cost are presented for each single category.

The cost-supply data are also assessable and downloadable from the S2BIOM tool box

Further methods used to provide estimates for imports are presented in a dedicated chapter in this report.

In the following the scope of the data base is further explained.

Current status and future potentials

The current status is referring to the year 2012. Future potentials are provided for 2020 and 2030.

Spatial scale

The data are provided for NUTS 3 statistical units that are formally defined for EU28 only. For the non EU other countries included equivalent administrative units have been defined per country (see D1.5 “Spatial data base on sustainable biomass cost-supply of lignocellulosic biomass in Europe”).

Spatial scope

Besides EU28, the western Balkan countries, Ukraine, Turkey and Moldova are included.

Type of Potential

Within S2BIOM potentials with several levels of constraints are determined, that are labelled technical, base and user defined potentials. They differ in the type of constraints that are considered. Two of them, the technical potential and the base potential are provided applying assumptions that are defined consistently across the different major origins, whereas the third type can be “composed” by the user applying selected constraints: The basic generic definitions are:

The technical potential represents the absolute maximum amount of lignocellulosic biomass potentially available for energy use assuming the absolute minimum of technical constraints and the absolute minimum constraints by competing uses. This potential is provided to illustrate the maximum that would be available without consideration of sustainability constraints.

The base potential can be defined as the technical potential considering agreed sustainability standards for agricultural forestry and land management. The base potential is thus considered as the sustainable technical potential, considering agreed sustainability standards in CAP (Common Agricultural Policy) for agricultural farming practices and land management and in agreed (national and regional) forestry management plans for forests (equivalent to current potentials described in EFSOS II). This also includes the consideration of legal restrictions such as restrictions from management plans in protected areas and sustainability restrictions from current legislation. Further restrictions resulting from RED (Renewable Energy Directive) and CAP are considered as restrictions in the base potential as well. CAP sustainable agricultural farming practices include applying conservation of Soil Organic Carbon (SOC) (e.g. Cross Compliance issues of ‘maintaining agricultural land in good farming and management condition’ and avoiding soil erosion).

The user-defined potentials vary in terms of type and number of considerations per biomass type. Following the general nomenclature of potentials the user defined potentials can also be considered as sustainable technical potentials but differ in the constraints considered vs the base potential and among each other. The user can choose the type of biomass and the considerations he would like to employ and calculate the respective potential accordingly. This flexibility is meant to help the user to understand the effect on the total biomass potential of one type of consideration against the other. These can include both increased potentials (e.g. because of enhanced biomass production) or more strongly constrained potentials (e.g. because of selection of stricter sustainability constraints).

Economic potentials using the cost-supply approach can then be determined using a price assumption and considering the road side costs per single category and NUTS3 area. The type of potentials determined by S2BIOM are illustrated in Figure 2. In the S2BIOM tool set the economic potentials are presented in form of cost-supply curves.

In addition, for forestry, a so called “high potential” is available. This shows a potential in between the technical and the base potential in order to demonstrate the potential availability of biomass from forests in the case of less stringent constraints on supply.

The definitions of potential levels are further detailed in the dedicated sections per major origin.

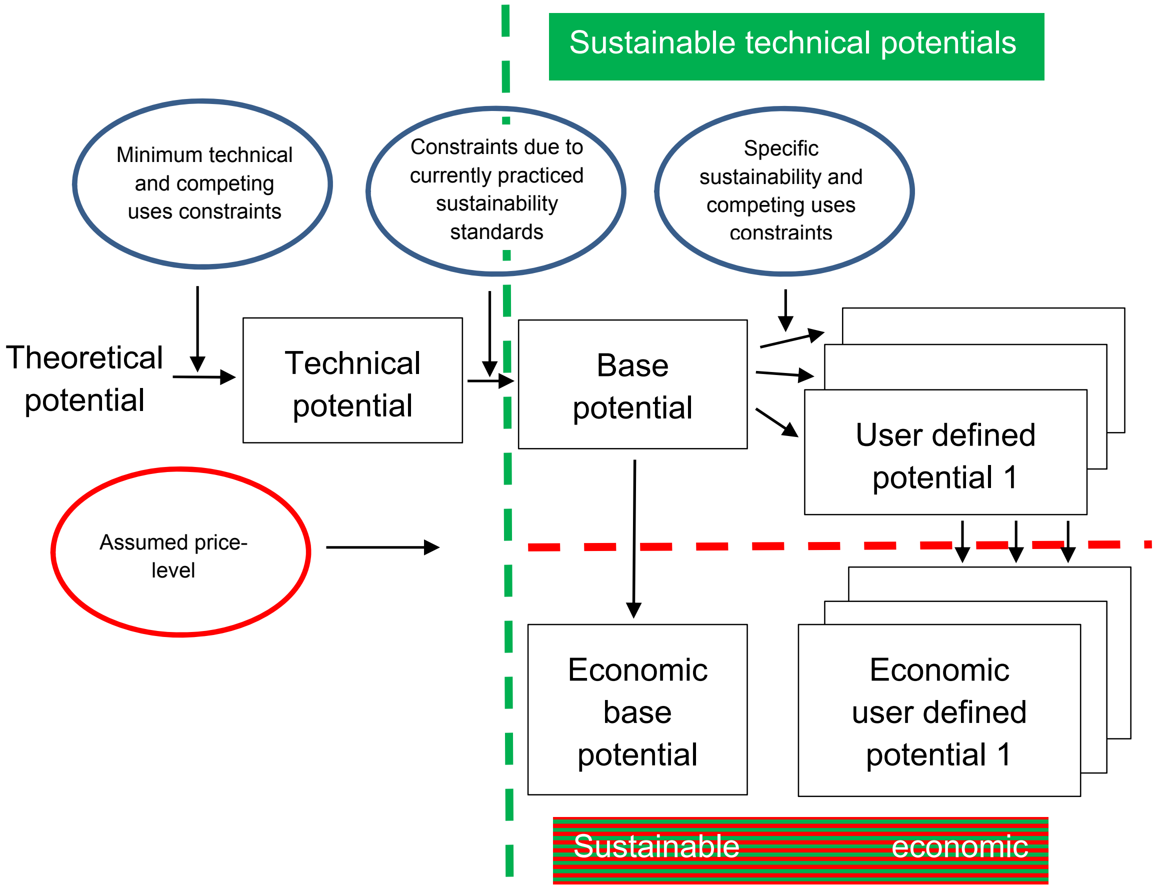


Figure 2 S2BIOM potential types

Methods to estimate costs

The industry emerging around the transition of fossil based feedstock for various forms of energy towards bio-based feedstock is in need of price level information now as well as in the future. Because we are still in the early stages of such a transition there is hardly any information of enough quality to conduct a meaningful market analysis. In this light it is important to keep in mind that a distinction needs to be made between different types of cost and price levels specific per biomass type:

- **Market prices** exist for already traded biomass types (e.g. straw, wood chips and pellets based on primary and secondary forestry residues).
- **Road-side-cost** for biomass for which markets are (practically) not developed yet (e.g. many agricultural and forestry residues, dedicated crops for ligno-cellulosic and woody biomass and waste streams such as vegetal waste). These may cover the following cost:
    - Production cost (in case of dedicated crops, not for residues or waste)
    - Pre-treatment in field/forest (chipping, baling)

    - Collection up to road side/farm gate

- **At-gate-cost** which cover the cost at roadside plus transport and pre-treatment cost of biomass until the biomass reaches the conversion plant gate (e.g. bioethanol plant, power plant).

The cost to be estimated as part of this Work Package 1 are limited to the **road-side cost**. So the cost from road side for transport and possible in-between treatment to the gate of the conversion installation or the pre-treatment installation are NOT included. The cost for the collection from the road-side to the gate as well as the pre-treatment costs are estimated in collaboration with WP 2, WP3, WP4 and WP7 for specific biomass delivery chains further assessed in models (ReSolve) and S2BIOM tools (BeWhere & LocaGIStics) included in the S2BIOM toolbox and applied in specific regional case studies.

The cost up to the road side includes the cost for production prior to harvesting, in case of dedicated perennial crops, crop establishment, fertilizing, crop protection, harvesting/cutting, uprooting, baling, shredding, chipping, crushing collecting and/or densifying in the point of harvest and bringing it to the main road side. Since we assume that dedicated feedstock will be grown mostly on marginal land (i.e. threatened by abandonment) these costs tend to be very low and are therefore neglected. Activities related to establishing the contract (transaction costs) and other overheads are not (yet) accounted for. These cost can be quite substantial. One way of dealing with this is to assume a fixed percentage on top of the calculated road side cost price (typically in the range of 20% - 50%).

As explained for many categories of ligno-cellulosic biomass the market for use in energy and other biobased products has not been developed yet. However some biomass types for which there is already large scale use in other then energy sectors, such as for stemwood, straw, used paper and cardboard, there is a market and a related price setting. This is however mostly determined by-non-energy uses, while the effect of increased demand for energy production and other new non-food products is still limited and therefore not well known. For other types of ligno-cellulosic feedstock, such as additional harvestable stemwood, primary forestry residues, dedicated perennial crops, the market demand is also still very limited or non-existent and cost estimates for using these for energy and other biobased products are mostly available from pilot situations. Overall, it should therefore be clear that the focus of this task should be on the road side cost to produce the feedstock. Price information collected, if available, was only used to evaluate the cost assessment and improve where necessary.

The overall methodology followed to gain insight in the minimum costs of production is the *Activity Based Costing* (ABC). It involves the whole production process of alternative production routes that can be divided in logical organisational units, i.e. activities. The general purpose of this model is to provide minimum cost prices for the primary production of biomass feedstock at the road side. ABC generates the costs of different components based on specific input and output associated with the choice of the means of production, varying with the local conditions and cost of inputs (e.g. labour, energy, fertilisers, lubricants etc.). Since the production of most biomass is spread over several years, often long term cycles in which cost are incurred continuously while harvest only takes place once in so many years, the Net Present Values (NPV) of the future costs are calculated. This provides for compensating for the time preference of money. To account for the fact that the cost are declining in different periods of time in the future the Net Present Value annuity is applied. In this way annual, perennial crops and forest biomass cost are made comparable (=all expressed in present Euros).

The cost are automatically calculated for all field operations per year in a 60-year cycle in the case of agricultural biomass. The cost of wood production were not considered in this study as these cost need to be allocated to the main product, while here the focus is on the cost of the residues. Cost are presented as NPV per annum and expressed in € per ton dm or per GJ.

It is also important to note that the costs calculated in here are at the farm level cost. We are aware that the costs for the next link in the value chain might be higher because of rent seeking behaviour. However, in this approach we did not take account of it as we did not include a profit margin.

As explained in the former cost of agricultural biomass are calculated for *Net Present Value annuity* taking a 60 year coverage period. These 60 years are chosen to fit all possible cycles in the cost calculation as 60 is fully synchronizable to 1,3,5,10,15,20,30 and 60 years cycles. Cost differences after that period are negligible. In this way, cost for biomass from residues and from dedicated crops can be assessed with the same model and can be made comparable.

First the Net Present Values of all activities are calculated as follows:

Formula:

$$\mathbf{NPv=Fv/(1+i)^n}$$

Where:

NPv = Net Present value
Fv = Future value
i = the interest rate used for discounting (set to 4%)
n = number of years to discount

Then the Net Present Value annuity is applied, assuming that the sum of NPVs cover the annual capital payments attracted against the same interest rate (4%) as the discount rate used for calculating the NPVs.

Formula:

$NPVa=\Sigma NPv*(1/((1-(1+i)^{-n})/i))$

Where:

NPVa = Net Present Value annuity
ΣNPv = sum of NPVs
n = number of years
i = the interest rate (set to 4%)

The cost also allow for national differentiation of cost according to main inputs having national specific prices levels. The is organised through the **'Country inputs'** module in the ABC model. It contains detailed information concerning the prices of various resources needed as input for the production process of biomass specific per country. These are specified, either in absolute price levels or as an index related to the known price level in one or two specific countries (mostly Germany). This is necessary as prices of key production factors differ a lot at national level across Europe. National level price data (ex. VAT) included cover cost/prices for labour (skilled, unskilled and average), fuel, electricity, fertilizers (N, P2O5, K2), machinery, water, crop protection and land. Most of these data were gathered from statistical sources such as FADN (Farm Accountancy Data Network), Eurostat and OECD. Most cost levels were gathered for the year 2012.

The cost data elaboration also requires a feedstock specific approach. If cost are estimated for biomass that is specifically produced for energy or biobased products, i.e. in the case of dedicated crops the cost structure is clear and all cost can be allocated to the final product. All cost should include the fixed and variable cost of producing the biomass including land, machinery, seeds, input costs and on field harvesting costs. If the biomass is a waste, i.e. cuttings of landscape elements or grass from road side verges, the cost could be zero, as cutting and removing these cutting is part of normal management. However, bringing the biomass to the conversion installation requires some pre-treatment costs, e.g. for drying or densifying and then transport costs have to be made to bring it to the conversion installation. These cost will not be assessed here however as we concentrate on the road side cost.

Crop residues also require a separate approach as harvesting cost can usually be allocated to the main products, i.e. grain in the case of cereal straw, and not to the residue. However, the baling of the straw and the collection up to the roadside can be included in the costs.

For the elaboration of cost levels account also needs to be taken of the local circumstances and type of systems used for the production and harvesting of the biomass. This is particularly complex in the case of dedicated crops for which cost estimates are mostly and/or only available from pilot plots and practically no commercial plantations. Costs vary strongly per type of management, soil and climate zone. Furthermore, cost need to be allocated per ton harvested mass over the whole life-time of a plantation as harvest levels are very low in the first years and increase in time.

The cost are determined for 2012, the reference year and are kept constant in the future years 2020 and 2030. The reason for keeping cost constant in time has several advantages:

1) Estimations of future changes in prices for (fossil) energy (fuel & electricity), labour, and machinery are difficult to predict. If predictions are used this implies automatically adding additional uncertainties in the cost assessment.
2) If cost levels do not alter in time the uses of the cost-supply data in other models in and outside S2BIOM (e.g. Resolve and BeWhere) deliver results that can only be explained from the internal logic of the models and not by differences in cost level increases based on a large number of uncertainties.
3) The cost levels presented in S2BIOM can still be further adapted by other users applying their own assumptions on future cost level changes. This enables them to use the S2BIOM cost-supply data consistently with their own modelling assumptions.

The following chapters are organised according to biomass categories. In one chapter a description of the methods for estimating biomass supply levels are combined with a more detailed description of cost level assessments.

2 Assessing the cost supply of lignocellulosic biomass from agriculture

2.1 Future agricultural land use and production predictions as a basis for agricultural biomass assessments

Since the assessment of agricultural residues and dedicated crops needs to be done for 2012 and for the future land use situations, we rely on economic and land use model output. The most logical model and dataset used as a basis for the estimation of future residual biomass supply from crops is the CAPRI model and related COCO database. The CAPRI model predicts the future market and production responses at the regional level for the whole EU-28, western Balkans, Turkey and Norway. It is therefore the only 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. Like was done in the Biomass Policies project in S2BIOM we therefore also build on the CAPRI model results both for assessing the amount of residues and for assessing competing use levels for straw by livestock. CAPRI forecasts future land use and livestock production changes in the EU-28, most Balkan countries (except Moldova) and Turkey including land demand for domestic biofuels (although NOT for bioenergy crop demand for bio-electricity and heat). Ukraine is not covered in CAPRI (except as part of the rest of the world for import and export relations with the EU).

For the assessment in S2BIOM (like for Biomass Policies) land-use and livestock production levels are used based on the most recent CAPRI baseline run 2008-2050, providing intermediate results for 2010, 2020, 2030 and 2050. This baseline run is seen as the most probable future simulating the European agricultural sector under status-quo policy and including all future changes in policy already foreseen in the current legislation. It also assumes all policy regarding bioenergy targets as agreed until now and further specified in the *Trends to 2050* report (EC, 2013)[1] for as far as affecting agriculture. For the assessment of residues the CAPRI land use patterns for 2010 were extrapolated to 2012 using FSS farm structural data and calculating relative crop area and livestock number changes between 2010 and 2012 and using these to extrapolate the CAPRI base data 2010 to 2012.

Yields and changes in yield levels per region and country in CAPRI for the conventional crops delivering residues are already included in the baseline scenario of CAPRI. They are derived from the Aglink-Cosimo modelling system of the OECD-FAO (see Britz and Witzke, 2012). The Member States fill in time series on future developments on several variables including yield developments of their main crops.

[1] EC (2013). *EU Energy, Transport and GHG emissions trends to 2050. Reference Scenario 2013*

These values are usually based on country specific modelling baselines, expert consultations, historic projections. The national input is then recovered in Aglink-Cosimo by adapting the behavioural equations in the model while at the same time adapting these to joint worldwide future development expectations regarding import/and export relations, worldwide price and technological developments. CAPRI then takes Aglink-Cosimo output as an input. These developments are then further incorporated into CAPRI but tuned where necessary with internal constraints set on yields for both vegetable and animal products. These internal constraints are needed to maintain a consistent and stable relationship between the very influential CAPRI specific yield increase parameters and other factors such as technology development, seed use and losses, land use ratio factors, etc. Further details on this aspect see Britz and Witzke (2012) and Elbersen et al. (2016ab).

2.2 Primary residues from agriculture

2.2.1 Potential categories and potential types

<u>General approach</u>

The potential supply of agricultural residues was estimated for the period from 2012, 2020 and 2030. It uses as main input the cultivated land and main crop production and yield combinations made for these years by the CAPRI model. For Ukraine and Moldova, not covered in CAPRI, we used national agricultural statistics at regional level. Residual biomass covered in S2BIOM from agriculture comes from primary residues from arable crops (straw and stubbles) and pruning, cutting and harvesting residues from permanent crops. (See Table 2).

Table 2 Subcategories primary agricultural residues

Third level subcategories		Final level subcategories		
ID	Name	ID	Name	Definition
221	Straw/stubbles	2211	Rice straw	Dried stalks of cereals (including rice), rape and sunflower which are separated from the grains during the harvest. Often these are (partly) left in the field.
		2212	Cereals straw	
		2213	Oil seed rape straw	
		2214	Maize stover	Grain maize stover consists of the leaves, stalks and empty cobs of grain maize plants left in a field after harvest
		2215	Sugarbeet leaves	The sugarbeet leaves and tops are the harvest residues separated from the main product, the sugar beet, during the harvest and (often) left in the field.
		2216	Sunflower straw	Dried stalks of cereals (including rice), rape and sunflower which are separated from the grains during the harvest. Often these are (partly) left in the field.
222	Woody pruning & orchards residues	2221	Residues from vineyards	The prunings and cuttings of fruit trees, vineyards, olives and nut trees are woody residues often left in the field (after cutting, mulching and chipping). They are the result of normal pruning management needed to maintain the orchards and enhance high production levels.
		2222	Residues from fruit tree plantations (apples, pears and soft fruit)	
		2223	Residues from olives tree plantations	
		2224	Residues from citrus tree plantations	

The assessment of residues from arable crops builds on methodologies and assessments already done in Biomass Policies and Bioboost. The assessment for vineyards, olive groves and fruit plantation residues bases builds on work done in EuroPruning *project.* The overall advantage of using agricultural residues is that it is a biomass with low ILUC risk. On the other hand there is also concern about what sustainable removal rates for straw and prunings, particularly in relation to maintaining the soil organic carbon (SOC) content.

At this moment, these residues are not always harvested and/or removed from the field and their mobilisation often requires changes in farming practices. Following this reasoning there are three types of potentials assessed (see also Table 3):

- The **Technical potential** represents the absolute maximum amount of lignocellulosic residues potentially available assuming the absolute minimum of technical constraints.
- The **Base potential** which takes account of what amount of residues are needed to keep the soil organic carbon (SOC) content stable. The rest of the biomass not needed for SOC maintenance can be removed and can be seen as potential. The assessment of this potential is done by using the MITERRA-Europe model (that calculates a carbon balance taking account of specific climatic and soil circumstances and yield levels at the average of a region (Nuts 2).
- The **User-defined (UD) potential** which for both straw, stubbles and prunings build on current practices and competing use levels.

Table 3 Overview of agricultural residual biomass potential types and considerations

	Area/ Basis	Yield, Growth	Technical & environmental constraints on the biomass retrieval (per area)	Consideration of competing use	Mobilisation
Technical (straw & stubbles)	Area in 2012, 2020, 2030 with cereals, rice, sunflower, rape, corn maize	Growth based on regional growing conditions & management. Yield according to regional averages including expected developments in yield towards 2020 and 2030	Maximum volume of straw and stubbles that could be harvested in 2012, 2020 and 2030	None	None
Technical (prunings permanent crops)	Area in 2012, 2020, 2030 with fruit trees, vineyards, olive & citrus	Growth based on regional growing conditions & management. Yield according to regional averages including expected developments in yield towards 2020 and 2030	Maximum volume of prunings and cuttings that could be harvested in 2012, 2020 and 2030	None	None
Technical (sugarbeet leaves & tops)	Area in 2012, 2020, 2030 with sugar beet	Growth based on regional growing conditions & management. Yield according to regional averages including expected developments in yield towards 2020	Maximum volume of sugarbeet leaves and tops that could be harvested in 2012, 2020 and 2030	None	None

	Area/ Basis	Yield, Growth	Technical & environmental constraints on the biomass retrieval (per area)	Consideration of competing use	Mobilisation
		and 2030			
Base (straw & stubbles)	As for technical potential	As for technical potential	Only the biomass part can be removed that is not needed to keep the SOC stable. This is assessed according to carbon content that is removed with the residue and the SOC level in the soil that has to be maintained.	None	None
Base (prunings permanent crops)	As for technical potential	As for technical potential		None	None
Base (sugar beet leaves & tops)	As for technical potential	As for technical potential	Removal of leaves and tops from field is only allowed in Nitrate vulnerable zones where nitrogen surplus needs to be declined through removal of nitrogen rich biomass.	None	None
User potential (straw & stubbles)	As for technical potential	As for technical potential	As in base	In cereal straw a subtraction is applied according to demand for straw for animal bedding & feed . For rice straw, corn stover and sunflower and rape stubbles not competing uses are assumed.	None
User potential (prunings & cuttings)	As for technical potential	As for technical potential	All pruned material is available that is currently according to real practices NOT used to maintain the SOC and fertility of the soil. So the part that is now removed to the side of the field for energy uses or that is burned with & without energy recovery is seen as potential and can be removed. This follows the common treatment practices of prunings as assessed in the EUROpruning project.	None	The potential that is NOT used for SOC and fertility maintenance according to current practices needs to be mobilised gradually as it requires a change in management. It is therefore assumed; it becomes available from 50% in 2012 to 60% in 2020 and 70% in 2030.

2.2.2 Assessing potentials for straw and stubbles from arable crops

In the following it is first explained how the technical potential for straw and stubbles is assessed followed by an explanation of how the sustainable potential is calculated using the MITERRA-Europe model. The last step is then to explain how the competing use of straw is estimated.

1) *Technical potential for straw and stubbles*

For the assessment of the technical potential we follow the methodology developed by the JRC already since 2006 (JRC and CENER, 2006 and Scarlat et al. 2009).

The calculation of the residue to yield factor, which is the factor applied to the main product yield to estimate the straw production from was calculated per crop type with the following formula:

residue yield = croparea * yield * residue2yieldfactor * DM_content.

Where:

- Crop area: derived from CAPRI per region for 2012, 2020 and 2030
- Yield level of the main product (seeds): derived from CAPRI as an average per crop per region
- Dry matter content is
  - All cereals: 85%
  - Grain maize: 70%
  - Rice: 75%
  - Sunflower: 60%
  - Oil seed Rape: 60%
- Residue to yield factors applied were specific per crop and were derived from Scarlat et al. (2009):
  - For soft wheat & durum wheat = -0.3629 - LN(yield) + 1.6057
  - For rye = - 0.3007 - LN(yield) + 1.5142
  - For oats = -0.1874 - LN(yield) + 1.3002
  - For oil seed rape= -0.452*LN(Yield)+2.0475
  - For sunflower= - 1.1097*LN(Yield)+3.2189
  - For grain maize= = -0.1807 - LN(yield) + 1.3373
  - For rice = -1.2256 - LN(yield) + 3.845
    - **LN(yield)**: refers to the natural logarithm of the yield level

Since the formula provided by Scarlat et al. (2010) applies to the whole above ground biomass a correction factor was additionally applied to assess the straw part only. The straw: stubble ratio can be highly variable, depending on crop type, cultivar and harvest management. Based on Poulson et al. (2011) and Panoutsou and Labalette (2007) an average straw stubble ratio of 55% : 45% was used. This implies that the final technical straw potential for all cereals requires the application of the above presented formula times **0.55** to come to a final straw technical potential. For rape, sunflower and grain maize this correction is **not** applied as not relevant.

2) Sustainable potential for straw and stubbles

The aim of S2BIOM was to identify the part of the residues that can be removed from the field without adversely affecting the SOC content in the soil. The soil organic carbon balance is the difference between the inputs of carbon to the soil and the carbon outputs. A negative balance, i.e. outputs are larger than the inputs, will reduce the SOC stock and might lead to crop production losses on the long term. To calculate the soil carbon balance at regional (NUTS2 level) we used the MITERRA-Europe model to provide the input data and the RothC model to calculate the soil carbon dynamics. Manure and crop residues are the main carbon inputs that were included. SOC decomposition has been included as the only carbon output, other possible C outputs, such as leaching and erosion, are not accounted for.

MITERRA-Europe model was developed for integrated assessment of Nitrogen, carbon and phosphate balances and emissions from agriculture in EU-27 at Member State and regional levels (NUTS-2). It is a simple and transparent model applying an uniform approach to assess impacts of changes in policies on the environment, taking CAPRI output (on changes in management and landuse) as starting point for analysis. MITERRA-Europe calculates GHG (CO_2, CH_4 and N_2O) emissions, SOC stock changes and nitrogen emissions from agriculture on a deterministic and annual basis. It is based on the CAPRI and GAINS models, supplemented with a nitrogen leaching module, a soil carbon module and a module for representing mitigation activities (Velthof et al., 2009; Lesschen et al., 2011; de Wit et al., 2014). The model comprises about 35 crops and 10 livestock categories. MITERRA-Europe covers the agriculture sector at different spatial scales, e.g. for Europe this consists of EU-27 scale, Member State scale and NUTS2 scale.

It is the carbon balance module that has been further adapted in S2BIOM (and Biomass Policies) to take account of removal of straw (and also prunings, see next). This was done by incorporating the RothC model (Coleman and Jenkinson, 1999) into MITERRA-Europe. RothC (version 26.3) is a model of the turnover of organic carbon in non-waterlogged soils that allows for the effects of soil type, temperature, moisture content and plant cover on the turnover process. It uses a monthly time step to calculate total organic carbon (ton C ha-1), microbial biomass carbon (ton C ha-1) and Δ14C (from which the radiocarbon age of the soil can be calculated) on a years to centuries timescale (Coleman and Jenkinson, 1999). For this study RothC was only used to calculate the current SOC balance based on the current carbon inputs.

In RothC model, SOC is split into four active compartments and a small amount of inert organic matter (IOM). The four active compartments are Decomposable Plant Material (DPM), Resistant Plant Material (RPM), Microbial Biomass (BIO) and Humified Organic Matter (HUM). Each compartment decomposes by a first-order process with its own characteristic rate. The IOM compartment is resistant to decomposition.

RothC requires the following input data on a monthly basis: rainfall (mm), open pan evaporation (mm), average air temperature (oC), clay content of the soil (as a percentage), input of plant residues (ton C ha-1), input of manure (ton C ha-1), estimate of the decomposability of the incoming plant material (DPM/RPM ratio), soil cover (if the soil is bare or vegetated in a particular month) and soil depth (cm). Initial carbon content can be provided as an input or calculated according to long term equilibrium (steady state).

The key input data sources used for calculating the soil balance per region and per crop were:

- SOC stock based on LUCAS data (0-20 cm) (see Figure 4): LUCAS, which stands for Land Use/Cover Area frame statistical Survey, is a harmonised survey carried out by EUROSTAT with the aim to gather information on land cover and land use across the EU. Estimates of the area occupied by different land use or land cover types are computed on the basis of observations taken at more than 270,000 sample points throughout the EU (EUROSTAT, 2015). For the second survey (2009), the European Commission extended it to sample and analyse the main properties of topsoil (Toth et al., 2013). This topsoil survey represents the first attempt to build a consistent spatial database of the soil cover across the EU based on standard sampling and analytical procedures, with the analysis of all soil samples being carried out in a single laboratory. Approximately 20,000 points were selected out of the main LUCAS grid for the collection of soil samples in 25 Member States of the EU. Bulgaria and Romania were sampled in 2012, but those data are not yet available. A standardised sampling procedure was used to collect around 0.5 kg of topsoil on 0-20 cm depth. The samples were sent to an accredited laboratory where a range of chemical and physical soil properties were analysed. SOC content (g C kg−1) was measured by dry combustion (ISO 10694:1995). The benefit of LUCAS data is that it is recently observed data and there is a clear link to land use. Soil bulk density was calculated by applying the pedo-transfer function of Hollis et al. (2012), as the LUCAS survey did not include its in-situ measuring. Based on these data the average SOC stock on arable land was calculated per NUTS 2 region (see Figure 4). Provides average soil properties for arable and grassland soils. Peat soils (>12% SOC) are excluded from LUCAS.

- Missing non-EU countries (all western Balkans, Ukraine and Turkey) data for SOC levels were filled with world and EU soil map data on soil properties.
- Climate data
  - Monthly temperature, precipitation and potential evapotranspiration which were derived from WorldClim and FAO (Hijmans et al., 2005). These data refer to 30-year averages of the period between 1960 and 1990. Monthly reference evapotranspiration was sourced from the Global map of monthly reference evapotranspiration provided by FAO's GeoNetwork. The data are in 10 arc minutes.
- Carbon inputs (data for 2010)
  - Manure (based on N flows and CN-ratio). The carbon input from manure, compost and sludge was derived from MITERRA- -Europe, following the allocation of manure nitrogen to crops and a livestock type specific CN ratios.
  - Crop residues (NUTS2 yield data (matched with CAPRI), harvest index (Vleeshouwers and Verhagen, 2002)

In MITERRA-Europe the C input is then quantified for four components:

1. Grain yield at NUTS2 level (Eurostat)
2. Above ground residues (according to Scarlat et al., 2010) as above
3. Straw : Stubble/chaff = 55:45 ratio

4. Belowground C input 25% of assimilated C (based on Taghizadeh-Toosi et al., 2014)

The C input from Manure and from the crop residues that is assessed in MITERRA-Europe is mapped in Figure 3. The eventual sustainable straw removal rate is then calculated by taking the balance between the level of carbon input from manure and residues that is needed to keep the SOC at a stable level. The resulting removal rate of the residues is presented in Figure 5.

1) Assessing competing use levels for straw

To determine the user-defined potential for straw that takes account of competing use levels for cereal straw, the current and future livestock uses for straw were quantified. For cereal straw competitive uses are for bedding in specific livestock systems (including horses). The exact quantification is done by using data on livestock type and number data from CAPRI baseline runs.

Scarlat et al, (2010) provided the following factors for straw use by animals:

* Equidae (horses) 1.5 kg straw/day.head

* Cattle 1.5 kg straw/day.head (1/4 of population)

* Sheep 0.1 kg straw/day.head

* Pigs 0.5 kg straw/day.head (1/8 of population)

Since Scarlat provided the average straw uses per animal group not distinguishing between different types of animals (young and grown-up animals) the averages were further transformed to the main animal sub-groups in CAPRI as follows:

Dairy_cows 0.375 kg straw/day.head

Beef_cows 0.375 kg straw/day.head

Pigs 0.0625 kg straw/day.head

Poultry 0 kg straw/day.head

Laying_hens 0 kg straw/day.head

Sheep_goats 0.1 kg straw/day.head

For the non-cereal straw types competition is not known and therefore competition levels were set at 0.

Figure 3 C input from manure (top) and from residues (below)

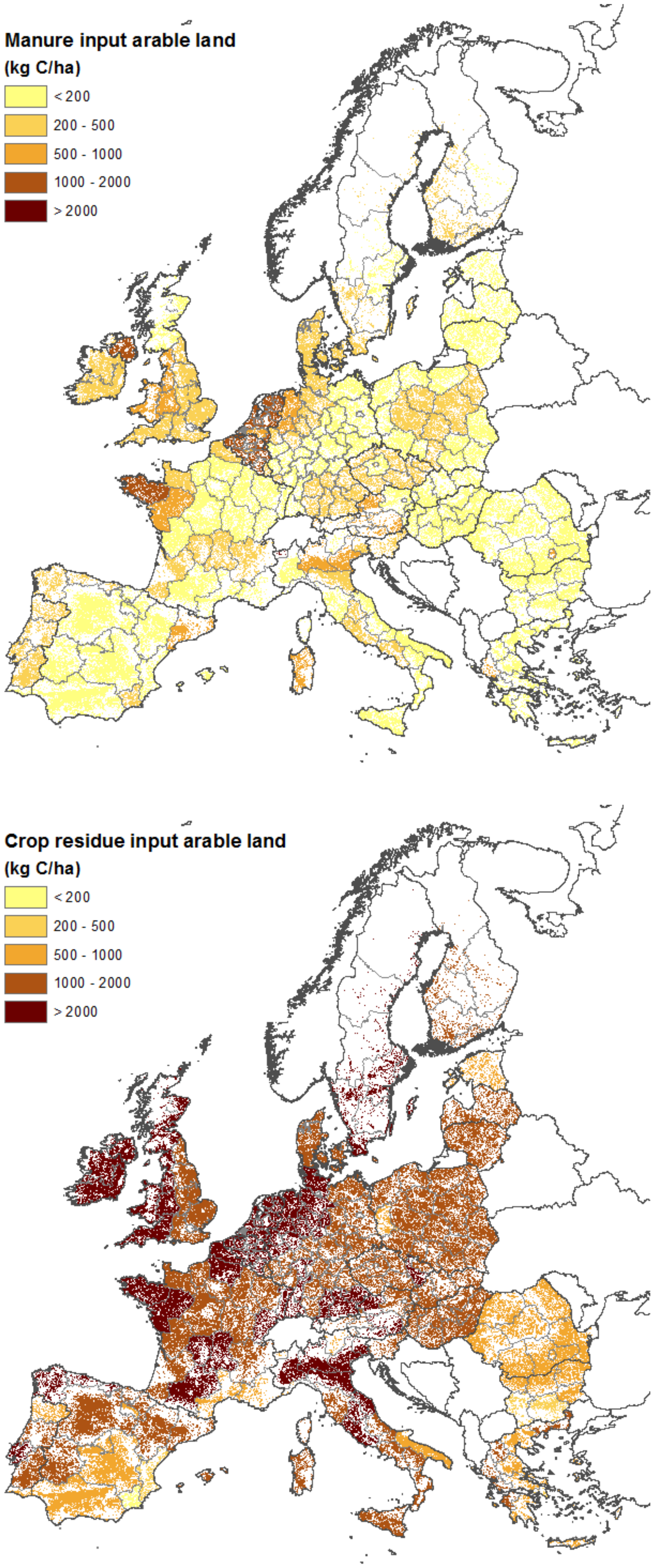


Figure 4 Current SOC levels (from LUCAS, 2010)

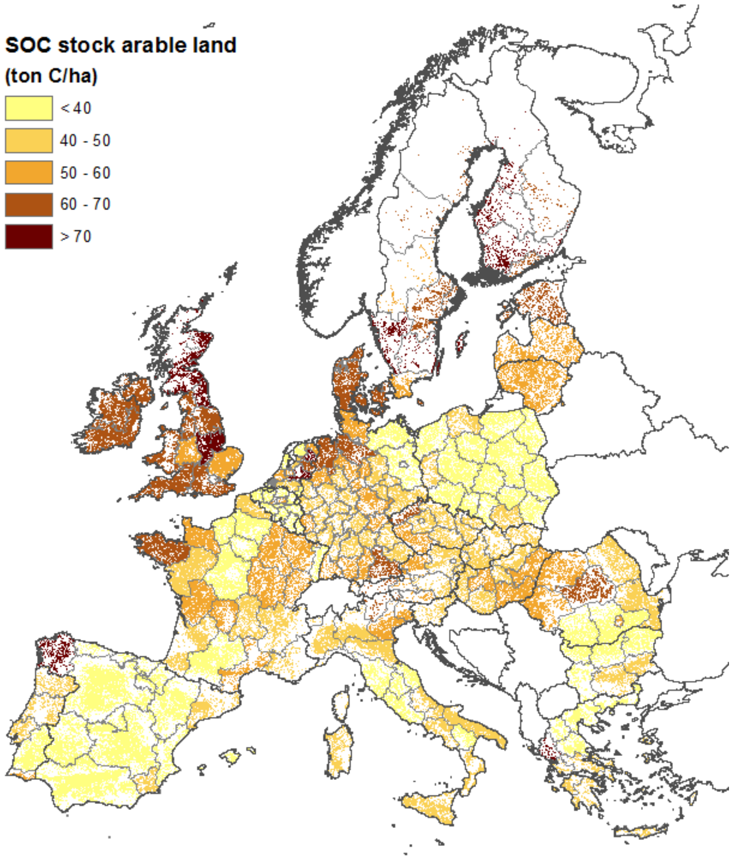
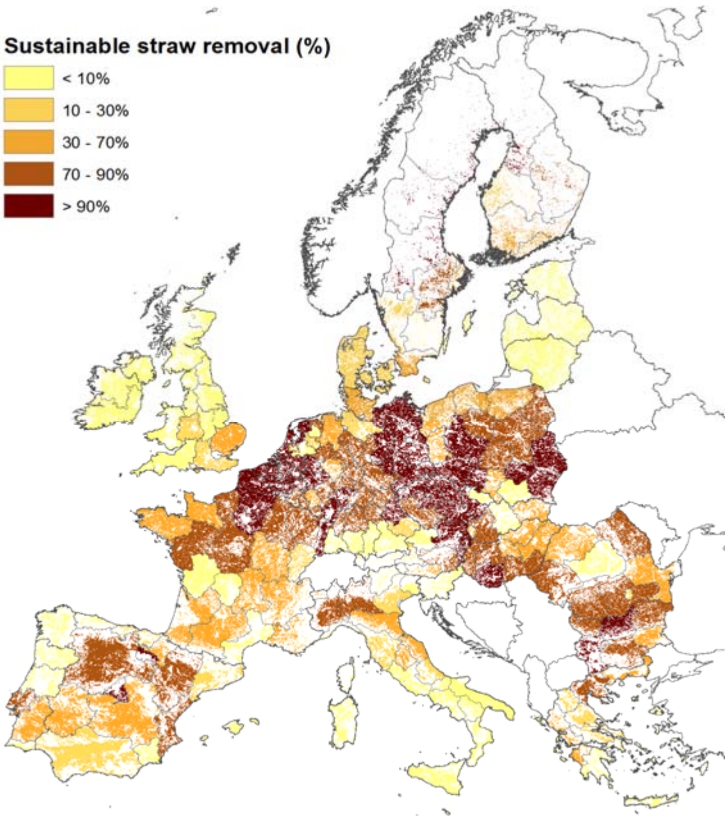


Figure 5 Sustainable residue removal rates as calculated by MITERRA-Europe



2.2.3 Assessing potentials for prunings and cuttings from permanent crops

The focus for estimating the biomass potential from permanent crops will be on the pruning material and not on the trees and stumps that can be removed at the end of a plantation lifetime. Pruning is part of normal practice to enhance and maintain the production of the main fruit and is therefore a cyclical activity delivering a stable amount of biomass every year.

In Europe the most important permanent crops delivering woody residues are fruit trees (apple, pear, cherries, apricots, peach etc.), vineyards, olives, citrus, berries and nuts. For the first categories of crops stable statistical data are collected on area and production levels in all European and national agricultural statistics but for berries and nuts plantations these figures are more challenging to find. The latter are therefore not included in the CAPRI baseline simulations and therefore not included in the pruning potentials assessed here.

The EuroPruning project report D3.1 (EuroPruning, 2014) contains estimates of pruning residues delivered by the different permanent crops but also confirms that there is a 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 as is already discussed extensively in Elbersen et al., 2016a. The EuroPruning project was therefore started in 2014 to exactly fill the gap in data and knowledge on the availability of pruning residues in Europe and develop and implement pruning based logistical chains. The best and most recent EU wide source of information on availability of pruning residues and current removal practices was produced as part of EuroPruning (EuroPruning, 2014) and therefore we used this information as a basis for estimating the technical potential of pruning residues.

In the following it is first explained how the technical potential for prunings and cuttings is assessed followed by an explanation of how the sustainable potential is calculated using the MITERRA-Europe model. The last step is then to explain how the current removal practices and competing uses are estimated.

1) *Technical potential for prunings and cuttings*

The overall calculation of the technical potential of pruning residues was done as part of the EuroPruning project (report D8.1: EuroPruning, 2016) and builds on what is called the Theoretical potential in EuroPruning. The first step that was taken in EuroPruning was to estimate the Residue to Surface Ratio (RSR) for different types of permanent crops at regional level. For this, data was collected as presented in EuroPruning D3.1 report (see Part II of the report, EuroPruning, 2014). On these data a statistical analysis was carried out on 230 records of pruning potentials sampled / surveyed for vineyard, olive, apple/pear, stone fruits, citrus and dry fruits prunings in 7 countries of Europe, namely: Spain, Italy, France, Germany, Poland, Greece, Portugal and Croatia. The aim of the correlation exercise was to detect correlations of multiple parameters (species, age, density, intensiveness, climate type, agro-climatic values) with the pruning potentials and from that determine a more general RSR (t/ha) value for each specific site. It turned out that limited correlations were found and the ones identified were weak and some were moderate. Those moderate ones were selected for a regression analysis, and regression equations were obtained for vineyards and citrus species, as described in the report D3.1 (EuroPruning, 2016) and further by García-Galindo et al 2016.

The second step was then to take the regression equations and use them to develop 'ramp functions' which implies that the linear regressions are translated into useful functions. These ramp functions combined with additional hypothesis and criteria were used to make spatial desegregations of the RSR factors over the whole of Europe (García-Galindo et al, 2016). The continuous raster coverages provided by IIASA/FAO, 2012 (agro-climatic potential) and CGIAR, 2012 (eco-crop suitability index) were used as the geographic layers (GIS basis). These agro-climatic coverages were then used to apply the ramp functions and .transform the permanent cropping areas in every zone into continuous coverages of pruning potentials (RSR, t/ha of dry matter).

A zonal statistical function was applied to obtain a summary of the average RSR ratios per crop species (temperate fruit, nuts, citrus, vineyard and olive) by region (NUTS2 and NUTS3). The average RSR ratios per NUTS were multiplied by the corresponding cultivated area reported by Eurostat for fruit species (temperate), citrus, nuts, vineyards and olives. From Eurostat[2] at NUTS2 data was obtained on the share of irrigation (%irr) in every permanent crop group. The use of the percentage of irrigation allowed to calculate the potential disaggregated in rainfed and irrigation land and then this was further transformed in RSR for rainfed (RSR_{rfed}) and RSR for irrigation (RSR_{irr}). The average RSR levels for irrigation and rainfed are presented in Table 4.

Table 4 National average maximum pruning yields per country (Irri=irrigated/Rfed=rainfed)

Ton dm/ha/year	Apples & pears		Grapes		Soft fruit		Citrus		Olives	
	Irri.	Rfed	Irri.	Rfed	Irri.	Rfed	Irri.	Rfed	Irri.	Rfed
AT	2.0	2.0	1.1	1.1	0.7	0.7				
BG	2.7	2.4	1.1	1.1	1.0	0.8	1.3	1.3	1.1	1.1
BL	2.0	2.0			0.7	0.7			1.1	1.1

[2] EUROSTAT. Regional statistics by NUTs classification. Data on Regiona agriculture statistics. "Structure of agricultural holdings" dataset. Data for year 2010. Available at: http://ec.europa.eu/eurostat/web/regions/data/database. Obtained in February 2016.

Ton dm/ha/year	Apples & pears		Grapes		Soft fruit		Citrus		Olives	
	Irri.	Rfed	Irri.	Rfed	Irri.	Rfed	Irri.	Rfed	Irri.	Rfed
CY	2.8	1.5	1.7	1.1	1.0	0.5	3.2	1.6	1.5	1.3
CZ	2.0	1.9			0.7	0.7				
DE	2.0	1.9	1.1	1.1	0.7	0.7			1.1	1.1
DK	1.6	1.5			0.5	0.5				
EE	1.5	1.5			0.5	0.5				
EL	2.8	1.7	1.5	1.1	1.0	0.6	1.8	1.6	1.3	1.3
ES	2.6	1.7	1.3	1.1	0.9	0.6	1.5	1.4	1.2	1.2
FI	1.5	1.5			0.5	0.5				
FR	2.4	2.2	1.1	1.1	0.8	0.8	1.3	1.3	1.1	1.1
HU	2.8	2.6	1.1	1.1	1.0	0.9				
IR	1.5	1.5			0.5	0.5			1.1	1.1
IT	2.6	2.2	1.2	1.1	0.9	0.8	1.4	1.4	1.2	1.2
LT	1.6	1.6			0.5	0.5				
LU	1.6	1.6			0.5	0.5				
LV	1.5	1.5			0.5	0.5				
MT	2.8	2.2	1.7	1.1	1.0	0.8	4.0	1.8	1.5	1.4
NL	1.7	1.6			0.6	0.6			1.1	1.1
PL	2.3	2.2			0.8	0.8				
PT	2.8	1.7	1.5	1.1	1.0	0.6	1.6	1.6	1.3	1.3
RO	2.6	2.4	1.1	1.1	0.9	0.8	1.3	1.3	1.1	1.1
SE	1.5	1.5			0.5	0.5				
SI	2.4	2.3	1.1	1.1	0.8	0.8	1.3	1.3	1.1	1.1
SK	2.3	2.2	1.1	1.1	0.8	0.8				
UK	1.5	1.5			0.5	0.5			1.1	1.1
HR	2.7	2.7	1.4	1.4	2.4	2.4	2.5	2.5	1.8	1.8
AL	3.5	3.5	1.8	1.8	4.3	4.3	2.5	2.5	1.8	1.8
BA	3.5	3.5	1.8	1.8	4.3	4.3				
MK	3.5	3.5	1.8	1.8	4.3	4.3			1.8	1.8
ME	3.5	3.5	1.8	1.8	4.3	4.3			1.8	1.8
RS	3.5	3.5	1.8	1.8	4.3	4.3			1.8	1.8
KO	3.5	3.5	1.8	1.8	4.3	4.3			1.8	1.8
UA	3.5	3.5	1.8	1.8	4.3	4.3				
TR	3.5	3.5	1.8	1.8	4.3	4.3	2.5	2.5	1.8	1.8
MO	3.5	3.5	1.8	1.8	4.3	4.3	2.5	2.5	1.8	1.8

Irri: Irrigated
Rfed: Rain fed
Source: EuroPruning project

In order to estimate the total pruning potential the EuroPruning RSRs for irrigation and rainfed crops were taken and combined in the following formula:

RESIDUE_YIELDi =

(AREAi * RSRrfed * % AREArfedi * DM_CONTENTi.) + (AREAi * RSRirr * % AREAirri * DM_CONTENTi.)

Where:

- RESIDUE_YIELDi = total pruning yield of rop i in Ton/Year in dry mass
- RSRirr = total pruning yield of irrigated crop i in Ton/Year in dry mass
- AREAi = Crop area of crop i
- % AREArfedi = share of area of crop I rainfed
- % AREAirri = share of area of crop I rainfed
- RSRrfed = Pruning yield for rainfed crop i in Ton/Ha/Year in fresh mass of crop i
- RSRirr= Pruning yield for irrigated crop i in Ton/Ha/Year in fresh mass of crop i
- DM_CONTENTi= Dry matter content of prunings of crop i

The harvest ratios for pruning were applied to crop area for the different permanent cropping areas (**AREAi**) from CAPRI baseline runs 2010 (extrapolated to 2012), 2020 and 2030.

The dry mass content of prunings (**DM_CONTENTi**) differs per type of crop and region, but as an average moisture content 40% (=0.6 DM_Content) was used for all permanent crops, with the exception of olives where it is 30% (= 0.7 DM-Content).

2) Sustainable potential for prunings and cuttings

Like for straw and stubbles a sustainable potential was defined by estimating the part of the residues that can be removed from the field without adversely affecting the SOC content in the soil. This is done through the calculation of a soil organic carbon balance which is the difference between the inputs of carbon to the soil and the carbon outputs. A negative balance, i.e. outputs are larger than the inputs, will reduce the SOC stock and might lead to crop production losses on the long term.

To estimate this MITERRA-Europe model was used again. For the overall methodology and model description and input data we refer to the former description of assessing SOC effects of straw removal with MITERRA-Europe (Section 2.2.2) The more specific model implementation for pruning residue removal rates is discussed in this Section.

The calculation of permanent crop specific removal rates was assessed in close collaboration with the EuroPruning. For perennial crops the C input from residues was differentiated into prunings, dead fruits, litter and belowground C inputs from roots (see Table 5 for the ratios assumed between the three and Figure 6 for an overview). In addition, C input from grassland cover in the permanent crop fields was also included. In order to estimate the grassland cover the LUCAS land use data (Eurostat, 2012) provided useful data. LUCAS provides crop and country specific shares of grass cover in orchards. For the grass yield, it was assumed that it amounted to half of the yield from normal grasslands in the same region which went together with half of the normal permanent grassland C input in the soil.

Table 5 Distribution ratios for total C input from prunings, dead fruit, litter and below ground input

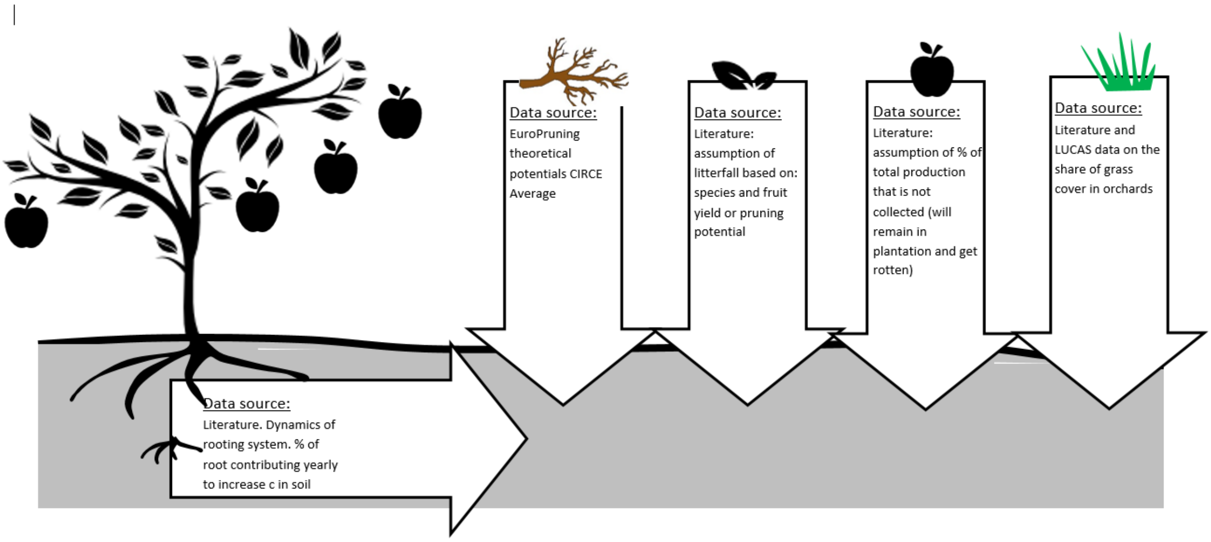
	RATIOS		
	leaf/fruit	**root death /fruit**	**root Derived C / fruit**
Olive	0,13	0,5	1
Vineyard	0,4	0,58	1,16
Fruit	0,32	0,23	0,46
Citrus	0,15	0,18	0,36
Dry fruit	0,25	0,4	0,8

Source: EuroPruning, report D8.1 (EuroPruning, 2016)

As for the C inputs of fruit losses data was not easily found, but data could be collected from four principal sources:

- Two studies worldwide orientated from FAO, 2011 and Aulakh, 2013
- Information gathered from several French data sources by SCDF, 2015
- A specific study developed in Spain for food losses (MAAM, 2015)

Figure 6 Carbon input from permanent crop residues



For estimating, the carbon input from leaves and litter fall a literature review was performed in EuroPruning (EuroPruning, 2016). For the non-perennial species (vineyards, dry fruits and fruit trees), it was assumed that the whole annual growth of the leaf organs will fall and become a potential source for organic carbon to the soil. In perennial species like olive and citrus, the canopy renovation rate was estimated. This was based on literature from which it could be derived that it amounted to about half to one third of the total leaf canopy. The value of one third was assumed to transform the structural weight of the leaf organs into annual growth.

The key input levels of carbon by roots were based on an extensive literature review in EuroPruning. A starting point for their review was Martínez et al. (2016) who summarised that root-derived C inputs (rhizodeposition) can be assessed through three main components:

BNNP = Increase of Coarse root + Increase of fine root + Root derived C.

Where:

BNNP=Belowground Net Primary Productivity (BNPP)

Root-derived C reflects the balance of root accumulation, root mortality (fine root and mycorrhizal turnover), and rhizodeposition (either from roots or mycorrhizal fungi).

So for these 3 sources of below ground C inputs, estimates were made from the literature (see Table 6 compiled in EuroPruning report D8.1, (EuroPruning, 2016)). The overall conclusion of the literature reviewed was that in general, the accumulation of annual growth on the permanent plant structure in vineyards, fruit trees and olive trees is rather small as compared to the NPP derived to the annual growth of fruit, leaf renovation and fine root dynamics and rhizodeposition.

Table 6 Summary of literature data employed in the assessment of the relations between Leaf and Fine Roots and the fruit yield

CROP	Literature sources
Citrus	Morgan et al. 2006; Morgan et al. 2014; Mattos et al. 2003; Feigeibaum et al. 1987; Alva et al. 1999; Mattos et al. 2003; Cannell et al. 1985; Churchill et al. 1986
Fruit	Sofo et al. 2015; Centritto et al. 2002; Grossman et al. 1994; Cannell et al. 1985; Inglese et al. 2002; Zanotelli et al. 2013; Martínez et al. 2016; Palmer et al. 1998; Psarras et al. 2000; Heim et al. 1979; Haynes et al. 1980; Chun et al. 2001; Yao et al. 2009
Olive	Sofo et al. 2015; Mariscal et al. 2000; Villalobos et al. 2006; Proietti et al. 2014; Hill et al. 2013; Almagro et al. 2010
Vineyard	Pitacco et al. 2015; Martínez et al. 2016(16); Smart et al. 2010
Dry fruit	No data obtained. Model obtained by observing the results for vineyard, citrus, olive and fruit trees.

Source: EuroPruning, report D8.1 (EuroPruning, 2016)

3) User defined potential for prunings and cuttings from permanent crops

In this approach we skip the carbon balance approach and look directly to what is the current practice of removal level and uses of what is removed. This information has been assessed in EuroPruning for the most important permanent crop producing countries in Europe. Since the EuroPruning only provided information for a selection of countries the practices for non-covered countries were copied from a neighbouring or similar countries (see Table 7). Prunings are an important source of nutrients and carbon but on the other hand there is also a risk involved when leaving pruning residues in the field as these can be a source of diseases in crops. Other practices quite common are to burn the pruning residues in the field without energy recovery. EuroPruning inventory (EuroPruning, 2014) showed that the way pruning residues are handled is very much dependent on the typical practices per crop and region and the regulations in place. Based on the EuroPruning project (D 3.1 report EuroPruning , 2014) national specific current use and removal practices were established to determine the levels of prunings that are 'shredded and left/incorporated in the soil' with the purpose to maintain nutrients & SOC in the soil (see Table 7).

From the inventory in EuroPruning the removal rates could be derived for the current 2012 situation per country. Since the EuroPruning only provided information for a selection of countries the practices for non-covered countries were copied from a neighbouring or similar country to cover the whole of Europe (see Table 7, last column and Table 8, second column).

Table 7 Current pruning management practices in Europe. The practice 'Shredded and left/incorporated to soil' refer to the level of prunings that are kept in the field for maintenance of SOC and nutrients in the soil.

Final use / disposal (%)	Olive	Vine-yard	Seed fruit	Stone fruit	Cherry	Citrus	Al-mond	Dry fruit	Country for which practices reported in EuroPruning (EuroPruning, 2014)
Piled and stored at field side*	0	2	0	1	1	0	2		ES
Piled and burned at field side*	90	95	95	97	97	85	97		ES
Shredded and left/incorporated to soil	5	1	5	2	2	10	1		ES
Local firewood*	5	2	0	0	0	5	0		ES
Commercialised for energy *	0	0	0	0	0	0	0		ES
Piled and stored at field side*		0	1	0				1	FR
Piled and burned at field side*		10	1	0				1	FR
Shredded and left/incorporated to soil		80	99	100				99	FR
Local firewood*		10	1	0				1	FR
Commercialised for energy *		1	0	0				0	FR
Piled and stored at field side*	0	0	0	0	0	0	0		IT
Piled and burned at field side*	90	35	85	85	85	95	50		IT
Shredded and left/incorporated to soil	5	35	15	15	15	5	20		IT
Local firewood*	5	30	0	0	0	0	20		IT
Commercialised for energy*	0	0	0	0	0	0	10		IT
Piled and stored at field side*		1	1	1					PL
Piled and burned at field side*		1	1	1					PL
Shredded and left/incorporated to		95	95	95					PL

Final use / disposal (%)	Olive	Vine-yard	Seed fruit	Stone fruit	Cherry	Citrus	Al-mond	Dry fruit	Country for which practices reported in EuroPruning (EuroPruning, 2014)
soil									
Local firewood*		3	3	3					PL
Commercialised for energy*		1	1	1					PL
Piled and stored at field side*	1	1	1	0			1		GR,NL,SK,SI
Piled and burned at field side*	1	1	1	0			1		GR,NL,SK,SI
Shredded and left/incorporated to soil	70	90	99	70			80		GR,NL,SK,SI
Local firewood*	30	10	1	30			20		GR,NL,SK,SI
Commercialised for energy*	1	1	1	0			1		GR,NL,SK,SI

*Seen as biomass potential now and/or in the future depending on mobilisation rate per year assumed

Table 8 Overview of unused pruning shares (=% already going to energy and/or not removed or used for soil improvement) in 2012 which are the results of an analysis of the data in Table 7.

	Country	Used factor (number refer to crop group number)	Apples, pears & other seed fruits	Cherry & other stone fruit	Citrus plantations	Olives	Vine-yards
BE	Belgium	NL (1,2)	2	30			
BG	Bulgaria	SK (1,2)/SI (4,5)	2	30		30	10
CZ	Czech Republic	SK (1,2)/SI (4,5)	2	30		30	10
DK	Denmark	NL (1,2)	2	30			
DE	Germany	NL (1,2), FR (6)	2	30			20
EE	Estonia	PL (1,2)	5	5			
IE	Ireland	NL (1,2)	2	30			
EL	Greece	EL	2	30		30	10
ES	Spain	ES (1,2,,3,4,5)	5	5	15	10	5
FR	France	FR/ES (4)	1	0		10	20
IT	Italy	IT (1,2,3,4,5)	85	85	95	95	65
CY	Cyprus	EL (1,4,4,5), ES (2)	2	30		30	10
LV	Latvia	PL (1,2)	5	5			
LT	Lithuania	PL (1,2)	5	5			
LU	Luxembourg	NL (1,2), FR (5)	2	30			
HU	Hungary	Average	2	30			
MA	Malta	IT (1,2,3,4,5)	85	85	95	95	65
NL	Netherlands	NL (1,2)	2	30			
AT	Austria	IT (1,2,3,5)	85	85			65
PL	Poland	PL (1,2), Average (3)	5	5			
PT	Portugal	ES (1,2,,3,4,5)	5	5	15	10	5
RO	Romania	AU (1,2,3,5)	95	95			95
SL	Slovenia	PL (1,2,3)/AU (5)	2	30			95
SK	Slovakia	PL (1,2,3)/AU (6)	2	30			95
FI	Finland	NL (1,2), Average (3)	2	30			
SE	Sweden	NL (1,2), Average (3)	2	30			
UK	United Kingdom	NL (1,2), Average (3)	2	30			
HR	Croatia	IT (1,2,3,4,5)	85	85	95	95	65

	Country	Used factor (number refer to crop group number)	Apples, pears & other seed fruits	Cherry & other stone fruit	Citrus plantations	Olives	Vine-yards
AL	Albania	UA (1,2,3,5), IT (4)	95	95	95	95	65
BA	Bosnia and Herzegovina	UA (1,2,3,6), IT (4)	95	95	95	95	65
MK	Macedonia	UA (1,2,3,6),IT (5)	95	95	95	95	65
ME	Montenegro	UA (1,2,3,6), IT (5)	95	95	95	95	65
RS	Serbia	UA (1,2,3,6), IT (5)	95	95	95	95	65
KO	Kosovo	UA (1,2,3,6), IT (5)	95	95	95	95	65
UA	Ukraine	UA (1,2,3,6), IT (5)	95	95	95	95	65
TR	Turkey	UA (1,2,3,6), IT (4,5)	95	95	95	95	65
M0	Moldova	UA (1,2,3,6), IT (4,5)	95	95	95	95	65

In this user defined potential the sustainable use which is subtracted refers to the part that is currently shredded and incorporated in the soil. The part that is now removed to the side of the field for energy uses and that is (first piled and then) burned in the field is seen as potential (see Table 7). This potential is expected to be gradually mobilised towards 2020 and 2030. This mobilisation of the unused potential gradually starts with 50% of the unused potential in 2012 and then increases by 10% in 2020 and again an extra increase of 10% by 2030.

2.2.4 Methods to estimate costs of agricultural residues

Straw and stubbles cost calculation

In S2Biom only the costs specifically made to produce the biomass for the non-feed or -food markets are considered. This means that in cases where there is a crop production for human consumption or for feed involved, such as wheat, this production will be considered the main product and the biomass for non-feed or food (e.g. straw in case of wheat) the by-product. All costs of growing the crop are attributed to the main product and consequently these become sunken costs for the by-product and thus excluded. Only activities specifically dedicated to the by-product (e.g. harvesting the straw) add to the (minimum) cost level of the biomass feedstock. Following this reasoning cost associated with land (e.g. land rent) are not attributed to the residual biomass. Only for dedicated feedstock the land rent becomes relevant (see next Section 2.3.3).

This means that in the case of straw and stubbles only the cost of harvesting, fertilization, because of nutrient removal with the straw, and baling and forwarding to the road side/farm gate are included in the calculation.

The cost for fertilization are needed to compensate for the loss of nutrients in the straw itself (i.e. not for the grains). These straw nutrients would otherwise be worked in the soil and act as fertilizer. So the cost for fertilization accounted for cover only part of the total fertilization cost of the cereal crop. In Table 9 an overview is given of the type of machines expected to be used for the harvesting of straw and maize stover. The larger machines are used in regions where larger fields dominate as identified per region in the Lucas database for the category of arable fields.

Table 9 Overview of machinery input for agricultural residue harvesting

Activity / treat	Type equipment	Capacity (low, medium, high)	Apt (t)	We (m)	V (km/h)	Time for loading/ unloading containers (min.)	Replace-ment value (€)	technical life (y)	rest value €	Depreciation rate (%)
harvesting /cutting	maize / willow cutter, 3m	L	0	3	2		58500	8	1	0.13
	maize / willow cutter, 6m	M	0	6	3		115000	8	1	0.13
	maize / willow harvester+ cutter, 9m self propelled	H	0	9	4		513000	8	1	0.13
harvesting/ combining	combine rotor 200 kw; 8500 ltr; 5m	L	10.5	5	4.5		241500	10	1	0.10
	combine rotor 350 kw; 12000 ltr; 9m	M	12	9	6		398000	10	1	0.10
	combine hybrid 400 kw; 12000 ltr; 12m	H	12	12	8		515000	10	1	0.10

Pruning cost calculation

In the case of prunings and cuttings from permanent crops we assume that the pruning activity itself is part of normal management of the main crop and the cost are therefore not allocated to the residues. What is included in the cost of pruning is the operations for obtaining the branches left on the soil, as shredded material at road side. For that purpose the operations are based on the existing mechanised technology, consisting of shredders of different types which are able to pick-up the branches, shred them, and convey into a big-bag, a built-in container, or an agrarian trailer towed behind the shredder. In addition the costs of gathering and transporting to the road-side also need to be calculated separately and for these cost levels the row distance between the crops is very influential.

Therefore as a first step an analysis was made in collaboration with the EUROpruning project of the average row distance in low, medium and high input systems was made for the different permanent crops in the different European countries. Subsequently an estimate needed to be made of the distribution of the different permanent crops over the 3 row size classes. This was done at Nuts 3 level by combining FSS permanent crop area information with the distribution of the area over different CORINE land cover (CLC) classes. Small fields with small row distances were expected to dominate in mixed CORINE land cover classes. The larger row sizes are likely to occur more in the CORINE classes with monocultures of permanent crops mapped separately as CLC classes: 'olives', 'vineyards', 'fruit trees and berry plantations'.

Beside the row distance estimates were also made of the average field size of the different permanent crops. This was again based on the Lucas database[3] as explained in the former. A relationship between field size and row distance was also assumed where larger fields go together with larger row distances and the other way around. The final choice of machinery is determined by the combination of row distance and dominant field size. So, the small fields with smaller row distances are low input and use the first machinery type in Table 10 i.e. the mulcher with big bag. In the larger fields with larger row distance it is possible to use the shredders/mulchers (front and rear) with a trailer. In the latter the efficiency is higher in terms of working time, but machinery cost in terms of replacement are almost twice as high (seeTable 10).

Table 10 Overview of machine mix used in low, medium and high input systems for pruning shredding/ mulching

Type equipment	Capacity (low, medium, high)	Apt (t)	We (m)	V (km/h	Time for loading/ unloading containers (min.)	replacement value (€)	technical life (y)	rest value €	De-preciation rate (%)
Shredder / mulcher (with big bag)	L	0.185	1.65	2.5	5	10000	8	1	0.13
Shredder / mulchers (rear bin)	M	0.5	1.9	4	6	17000	10	1	0.10
Shredder / mulchers (front/rear + trailer)	H	2	2.2	5	10	30000	10	1	0.10

2.3 Dedicated cropping of lignocellulosic biomass on unused lands

The large scale production of dedicated perennial biomass crops is still very limited. Estimates of the area of existing plantations were made in ETC-SIA (2013) and Elbersen et al. (2012) and indicated that in the EU-27 there were 5.5 million hectares used for dedicated biomass crops (for energy) and the dominant share (81%) was for oil crops (rape and sunflower) while only 1% was used for perennial biomass crops. This illustrates that perennials are not easily be fitted into existing arable cropping land. Also for the future the likeliness that increased demand for lignocellulosic biomass will lead to large production of perennials on existing good quality arable

[3] LUCAS database, 2013, Eurostat (http://ec.europa.eu/eurostat/statistical-atlas/gis/viewer/?myConfig=LUCAS-2012.xml). LUCAS data used are from the LUCAS 2012 Survey. It provides a distribution of agricultural Corine land cover classes (e.g. arable, permanent crops, olives etc.) over 4 parcel classes: <0.5 ha, 0.5-1 ha, 1-10 ha and > 10 ha.

lands is rather low. Firstly, because these perennials cannot compete with food and feed crops unless low productive soils are involved where perennials may give higher yields and returns. Secondly, farmers are usually not willing to lose their flexibility by turning their land into long term perennial plantations. After all they want to flexibly respond to market changes. Perennial plantations with a long lifetime of 15 to 20 years do not fit with this preference. Thirdly, perennials are on the other hand promising as many types have the capacity to still deliver relatively high yields and considerable higher yields of biomass on lands of lower quality, that only give minor non-competitive yields for rotational crops[4]. The lower quality lands are usually on the soils that first go out of agricultural use.

If a market indeed develops for lignocellulosic crops it is likely that the lands that are no longer used for conventional cropping with food and feed crops is partly used for production with biomass crops like miscanthus, switchgrass, giant reed, reed canary grass and SRC crops. For potential assessment of perennials it is therefore logical to consider the lands that are not/no longer productively used for food and feed production and that are often strongly overlapping with marginal lands (as defined by JRC, Oorschoven et al., 2013 and Terres et al., 2014 ab).

2.3.1 Potential categories and potential types

The potential supply of lignocellulosic crops and SRC was estimated for the period 2012, 2020 and 2030 for yield and production cost (see subcategories, Table 11).

Table 11 Subcategories “Primary production of lignocellulosic biomass crops

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
211	Energy grasses, annual & perennial crops	2111	Biomass sorghum (Annual grasses)
		2112	Miscanthus (Perennial grass)
		2113	Switchgrass (Perennial grass)
		2114	Giant reed (Perennial grass)
		2115	Cardoon (Perennial crop)
		2116	Reed Canary Grass (Perennial grass)
212	Short rotation coppice	2121	SRC Willow
		2122	SRC Poplar
		2123	Other SRC

The data, relevant work on biomass crop selection and performance has been done and is being done in larger EU projects. A lot of valuable material is generated in these projects on identifying the best suitable perennial crops for bioclimatic and soil diversity in Europe in experimental fields and wider meta assessments by European crop experts (Table 12). A selection of the relevant projects that are already providing

[4] As was already shown in projects like 4FCROPS, OPTIMA, OPTIMISC, WATBIO, SEEMLA, SRC plus, BFF, BioC4, MISCOMAR, and FIBRA

and will provide valuable information on best suitable crops and their performance in the near future are:

Table 12 Input projects and data sources

Group	Type of biomass	General methodology for quantification of potential	Main data sources/ models	Relevant studies/ projects	Main sustainability aspects
Ligno-cellulosic crops/Woody	Miscanthus Switchgrass Reed Canary Grass Cardoon Giant reed Poplar Willow Eucalyptus	Statistical/ modelling/ GIS analysis/ GAMS	Eurostat and national agricultural crop and land use statistics. Models like: CAPRI, MITERRA-Europe, LUCAS, HNV, CLC, FADN	4Fcrops, FIBRA, OPTIMA, Crops2Industry, Crops2water, Biomass Policies	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

Theoretical potential (yield potential) was defined as the maximum amount of crop biomass that could be annually harvested from all lands that are no longer productively used for food and feed production (released land, fallow, abandoned often overlapping with marginal lands).

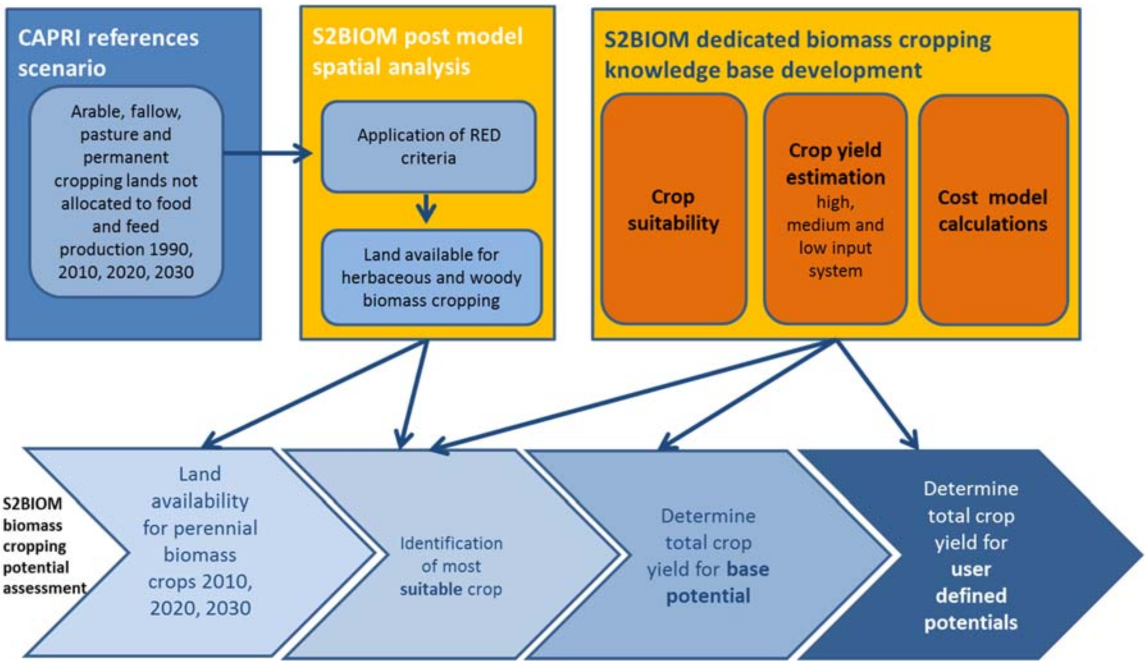
2.3.2 Methods to estimate the supply potential

Identification of land availability in CAPRI

For the land availability we will build on the CAPRI model assessment predicting changes in agricultural markets and land use. This data source was also used in the Biomass Policies dedicated cropping assessment (Elbersen et al., 2016) but the approach has been elaborated further as discussed in the following.

In the S2BIOM project for the assessment of the dedicated biomass cropping potentials the land no longer used for agriculture, as assessed by the CAPRI model for the baseline scenario are taken as a potential land resource for woody and herbaceous biomass cropping (this CAPRI model was described already in the former in Section 2.1). From CAPRI, only the land availability for these crops is taken, after a post model assessment was made, and this land is then combined with data generated in the S2BIOM project on biomass crop yields and ABC-net present value cost calculations (see Chapter 1 in this report). This combination delivers the final biomass potential for these crops in Europe (see Figure 7). The large advantage of using the land claim for these crops from CAPRI is that it has been identified taking account of competing land use claims from other activities, such as for food, feed, and urbanization.

Figure 7 Integration of CAPRI land availability for dedicated biomass crops with S2BIOM yield and production cost level assessments to estimate herbaceous and woody biomass cropping potentials



The RED criteria specified in Table 6 have been selected for the identification of land suitable for the production of woody and herbaceous crops per location. In this project a wider interpretation of the RED criteria is followed. Currently the RED criteria are only applicable to biomass used for the production of biofuels, but in this project these are applied to all biomass used for non-food applications. The application of certain RED criteria is dependent on the type of potential involved. In the Technical potential the RED criteria are hardly relevant except for the inclusion of lands that have been registered as agricultural since 1990 and lands that are not used for productive activities in order to avoid indirect land use change effects. The user defined potential is the most strictly restricted one.

For the assessment of the base potential, the following criteria are guiding the land suitability and allocation (see also Table 13):

1) Avoid competition with food and feed production for the economic and sustainability considerations already discussed in the former. Overall it is clear that mobilisation of perennial biomass cropping is not expected to take off on good agricultural lands, but rather low productive and often marginal lands.
2) Make the sustainability criteria for biofuels applicable to solid and gaseous biomass sources to be used for the generation of bio heat, electricity and biobased chemicals and materials (see next on application of RED criteria).
3) Integration of CAPRI unused land availability with perennial cropping yields, water requirements and NPV cost levels.

Table 13 (RED) sustainability criteria for assessing land available for dedicated biomass crops

RED criteria:	Rules implemented to assess land availability & selection of suitable woody & perennial crops	Technical potential	Base potential	User defined potential
No loss of habitat of high biodiversity value	Exclusion of use of Natura2000 areas & other protected areas		X	X
	Exclusion of use of High Nature Value farmland		X	X
No use of areas of high carbon stock lands	Exclusion of wetlands & peatland areas		X	X
	Only use lands that have been registered as agricultural since 1990 which ensures exclusion of continuous forest lands	X	X	X
	Exclusion of permanent grasslands (even if released from agriculture as assessed by CAPRI)		X	X
Avoidance of direct land cover changes	Only use lands that have been registered as agricultural since 1990 and marginal and polluted lands (as identified y JRC). This ensures exclusion of continuous forest lands, urban lands, recreational areas etc.	X	X	X
	Avoid conversion of permanent grasslands to arable		X	X
Avoidance of indirect land use changes	Only use surplus (agricultural) lands and marginal and polluted lands	X	X	X
Support agro-biodiversity	Avoid use of Natura2000 & HNV farmland (even if released from agriculture as assessed by CAPRI)		X	X
	Avoid conversion of permanent grasslands to arable		X	X
	No use of fallow land if fallow land share (in total arable land) declines to < 10%			X
	Avoid monoculture choosing mix of at least 3 perennial crops per region (covering both woody and herbaceous crops)		X	X
Avoid negative impacts on soil quality & enhance soil quality impacts	Maximum slope limits to perennial plantations		X	X
	Use perennial plantations to protect soil susceptible to erosion		X	X
	Use perennial plantations for bio-remediation of polluted soils			
Avoid negative impacts on water resources	Only use crops where minimal water requirement is delivered through annual precipitation (so irrigation is allowed but water depletion is avoided)		X	X
	No use of irrigation in perennial crops			X
	Preference for water use efficient crops in drought prone regions			X
Avoid competition with food	Only use surplus (agricultural) lands	X	X	X

As to the RED criteria they include restriction on biomass production in protected areas (national and international), restriction on areas with high biodiversity value (Natura 2000 and HNV farmland) and lands with high carbon stock (primary forest and wooded land, wetlands and peatlands). RED also promote the use of surplus land and this is followed up in all three potentials. The RED Directive also sets a maximum slope limit for cultivation and requires that only perennial crops can be grown on sites susceptible to soil erosion; that management practices (crop choice and yields) should be adapted to local biophysical conditions, particularly they should not lead to depletion of natural water resources. In addition, they should also enhance agro-biodiversity and lower soil erosion risk which prescribes location where these crops should and should not be grown, what crops choices can best be made and what management practices are required.

The User Defined potential includes all RED sustainability criteria applied in the Base potential and 2 additional: a total ban on irrigation water use in dedicated crops and a maximum to fallow land conversions in order to maintain & enhance a minimal share of fallow share of 10% in arable land in every region (see Table 13). The latter measure aims at enhancing agro-biodiversity. For several species the presence of fallow lands, especially long term fallow is important.

Identification of land suitable for herbaceous and woody biomass crops in different potentials

For the identification of potentially available lands for herbaceous (miscanthus, switchgrass, giant reed, reed canary grass and cardoon) and woody (SRC: poplar, willow and eucalyptus) crops the following land categories and information layers are used (see also Figure 7 and **Fehler! Verweisquelle konnte nicht gefunden werden.**):

1) Land availability based on the CAPRI agricultural markets and land use change simulation modelling for the reference scenario (2008-2030). By only taking the released and unproductively used lands from CAPRI it is ensured that the full demand for food and feed is first fulfilled. Many of these lands that go out of agricultural production/are abandoned are in the marginal range and are characterised by one or more marginality characteristics as identified by JRC (Oorschoven et al., 2013 and Terres et al., 2014 ab). These marginality factors include dryness, shallow soils, limited soil drainage and excess moisture, unfavourable soil texture and/or stoniness, steep slopes and salinity and acidity of soils. For most perennials crops these marginal factors, if not too extreme, do not need to be a limitation. However, depending on the marginal factors present some perennials can cope better with specific limitations then others. This is accommodated too in a final perennial crop mix selection as described further under 3). The following categories of released and/or non-productively used agricultural lands are available from CAPRI per type of potential:
    a. Technical potential:
        i. All good and low productive agricultural land released between 2008-2012, 2008-2020, 2008-2030
        ii. All permanent grassland released between 2008-2012, 2008-2020, 2008-2030
        iii. All fallow land available in 2012, 2020 and 2030 respectively
        iv. **No limitation** of above land categories according to environmental or economic considerations
    b. Base potential:

i. All good and all low agricultural land released between 2008-2012, 2008-2020, 2008-2030

ii. All fallow land available in 2012, 2020 and 2030 respectively

iii. Limitation of above land categories according to (RED) environmental considerations as specified in Table 6

c. <u>User Defined potential</u>:

i. All land available in the base potential for dedicated crops with the exception of fallow land below a 10% fallow share in the arable land area in 2012, 2020 and 2030. Fallow land must first reach 10% of the arable land.

ii. Only rainfed crop production is allowed. Crops that need irrigation in arid regions cannot be used.

2) **No-Go areas** are lands excluded because of policy constraints related to RED (Table 14) on the use of high biodiversity and carbon stock lands were translated into maps to identify which shares of the released agricultural land categories should be excluded from use for dedicated biomass cropping. The data layers used to identify these 'no go' areas were nationally protected areas and Natura 2000 sites and HNV farmland all mapped by EEA (2013) and JRC (Paracchini, 2009) and high carbon stock land identified by selecting the high carbon stock soils from the European soil map that overlap with CORINE agricultural land cover classes.

Table 14 No-go areas according to RED and bio-physical constraints

No-go area consideration per scenario	RED and bio-physical exclusion criteria & assumptions for mapping	Source
High biodiversity lands are excluded from the land availability in the *baseline, strict sustainability* and *realistic mobilisation scenario*	HNV farmlands in EU are mapped using agricultural Natura 2000 areas overlapping with CORINE agricultural land cover classes. A likeliness score for HNV farmland has been determined per region (Nuts 2/3) for arable and permanent grassland was mapped. It is assumed that the HNV farmland share for released agricultural land is similar to the average share for a region.	HNV farmland likeliness map: Paracchini et al., 2009. CLC 2012: EEA, 2012.
Land released in the permanent grassland category cannot be used for dedicated cropping because of risk of soil carbon loss in the *baseline, strict sustainability* and *realistic mobilisation scenario*	CAPRI land use changes between 2008, 2012, 2020, 2030 can be tracked per land use class by calculating a net land use change balance assuming shifts between good productive lands (used for rotational crops, fruit crops and temporary grassland) and lower productive lands (used for other permanent crops e.g. vineyards, olives, nuts etc. and permanent grasslands). Based on this balance it can be estimated how many permanent grassland areas go out of production between 2008 and 2012, 2020 and 2030 respectively. These releases are not to be used for dedicated cropping.	CAPRI land use change baseline results 2008, 2010, 2020 & 2030.
Fallow land if the total fallow land share in arable land is below 10%	Fallow land share in 2012, 2020 and 2030 can be calculated from CAPRI baseline per NUTS2 region by dividing the fallow land by the total arable land in different years. If the share is below 10% no fallow land can be used for dedicated cropping. If the fallow land share is above 10% the land up to	CAPRI land use change baseline results

No-go area consideration per scenario	RED and bio-physical exclusion criteria & assumptions for mapping	Source
	10% of fallow land share can be used for dedicated cropping.	

3) **Land suitability** refers to land with no or low suitability for one or more types of perennial biomass crops. In the two-steps above the land availability is limited by specific environmental factors from the RED. In addition, it will also be necessary to determine which crops are suitable per type of land, particularly given the strong overlap with marginal conditions abandoned agricultural lands are likely to have. To address this suitability maps were prepared masking (part of) the regions that are not suitable for specific crops because of climatic and or bio-physical limitations. For the elaboration of these spatial masks a matrix was developed matching the classified soil and climate limitations with the specific crop requirements. The selection of parameters and classes builds on the JRC study (Confalonieri et al. 2014) but has been refined using several references specified under Table 8. In Table 8 the scoring per perennial crop is presented. The combination of factors scoring 'low suitable' are completely masked out on a map for the specific crop (see Annex 2). A differentiation is made between soil and topographic characteristics (slope, soil depth, texture and soil pH) and climatic factors (temperature, precipitation and killing frost).

The score per bio-physical indicator being in the marginality range (as defined in Oorschoven et al. 2013 and Terres et al., 2014ab) starts with a slope above 8%, a soil depth of less than 80 cm, a soil txture with heavy clay or peat, a soil pH below 6, very large ranges in minimum and maximum temperature in growing seasons (>30°C), very low precipitation levels (<500 mm) and a very short growing season because of many frost days (see Table 15 and 16). Basically one can regard factor classes on which all perennial crops score '0' or '1' as good indications for extreme marginality. At the same time, it also becomes apparent that marginality does not need to be an impediment for certain perennial crops. For example, all perennials and SRCs types can generally grow on steeper slopes than the slope level rotational arable crops can cope with. This is related with denser soil cover and deeper rooting and lower (mechanisation) input requirements lowering the risk for soil erosion. Furthermore, many perennials can even be used to prevent erosion. Low precipitation/dryness is another factor many perennials can cope well with. This is particularly the case for cardoon and also switchgrass and giant reed. Of course this also goes together with lower yields, but these crops are still able to survive with very low precipitation levels, while this would certainly not be the case for most if not all rotational arable crops. SRC willow and poplar are however more sensitive to limited water availability. They actually have a preference for relatively wet soils which are not well drained, so these crops even do better under these marginal circumstances many other crops cannot cope with. On the other hand if the water holding capacity of the soil is bad and there is low precipitation (<500 mm) SRC willow and poplar crops cannot be grown there.

Some perennials can also cope with very heavy clay, which is particularly the case for giant reed, RCG and eucalyptus SRC. Acidity is also less of a problem for all perennials as compared to most rotational arable crops. Too shallow soils however, is a challenge for all perennials because of their deep rooting requirements.

Table 15 Soil limiting factors per perennial crop used to generate suitability masks

	Classes	***Mis-canthus***	***Switch-grass***	***RCG***	***Giant reed***	***Cardoon***	***Willow***	***Poplar***	***Eu-calyptus***
Slope (%)	<4 %	4	4	4	4	4	4	4	4
	4-8	3	3	3	3	3	3	3	3
	8-15	2	2	2	2	2	2	2	2
	15-25	1	1	1	1	1	1	1	1
	>25 %	0	0	0	0	0	0	0	0
Soil depth (cm)	Shallow *(< 40 cm)*	0	0	0	0	0	0	0	0
	Moderate *(40 - 80 cm)*	1	1	1	1	1	1	1	1
	Deep *(80 - 120 cm)*	2	2	3	2	2	2	2	2
	VeryDeep *(> 120 cm)*	4	4	4	4	4	4	4	4
Texture	Sand *(coarse)*	2	2	1	2	2	2	1	1
	Loam *(medium-medium fine)*	4	4	4	4	4	4	4	4
	Clay *(fine)*	2	2	2	3	2	2	2	2
	Heavy clay *(very fine)*	1	0	1	2	0	0	0	2
	Peat *(no mineral texture)*	0	0	0	0	0	0	0	0
Soil pH	0-4	0	0	0	0	0	0	0	0
	4-5	1	1	1	1	0	1	1	1
	5-6	3	2	3	2	2	2	2	2
	6-7	4	4	4	4	4	4	4	4
	7-8	2	2	2	2	3	3	3	3
Minimum an d maximum temperature in growing season in (°C)	0-5	0	0	0	0	0	0	0	0
	5-8	1	1	1	0	0	1	1	0
	8-10	2	2	2	1	1	2	2	1
	10-20	4	4	4	3	3	4	4	3
	20-30	3	3	2	4	4	2	2	4
	Max tem: >30	1	1	0	2	2	0	0	2
Precipitatio n (mm)	0 - 300	0	0	0	0	0	0	0	0
	300 - 400	0	0	0	0	1	0	0	0
	400 - 500	0	1	0	1	2	0	0	0
	500 - 600	2	2	0	2	3	0	0	1
	600 - 800	3	3	2	3	3	2	2	2
	800 - 1000	3	4	3	4	4	3	3	3
Killing frost (°C)	>-20	0	0	2	0	0	2	2	0
	-20	0	2	2	0	0	2	2	0

	Classes	Mis-canthus	Switch-grass	RCG	Giant reed	Cardoon	Willow	Poplar	Eu-calyptus
	-10	2	2	2	0	0	2	2	0
	-5	2	2	3	2	2	3	3	2
	0	3	3	3	3	3	3	3	3

**Note*: The scoring on the different bio-physical factors is classified as follows: “0” unsuitable, “1” low suitability, “2” medium suitable, “3” suitable,”4” very suitable.

Scores at level 0 or 1 are in the ‘marginality range’ according to Oorschoven et al (2013) and Terres, et al. (2014ab)

Source: Biomass future Project 2010; 4fcrop Project 2011; Confalonieri et al. 2014; Zegada-Lizarazu et al. 2010; Perpiña Castillo, C. et al., 2015; Eliasson et al. 2010; EU-JRC 2013; Allen et al. 2014; El Bassam 2013; James A. Duke (1983); Nsanganwimana F. et al 2014; Aust et al. 2014; Fernandez J. 2009; Zegada-Lizarazu and Monti 2012; Alexopoulou et al. 2015; Hopp et al. 1990; El Bassam 2013; Angelini et al. 2009; Zub & Brancourt-Hulmel 2010; Lewandowski et al. 2003; Fernandez J. et al. 2006.

Table 16 Killing frost limiting factors applied used to generate suitability masks

Killing frost	*Miscanthus*	*Switchgrass*	*Giant reed*	*RCG*	*Cardoon*	*Willow*	*Poplar*	*Eucalyptus*
Winter (>5days)	-10	-20	0	-30	0	-30	-30	0
Spring (>2 days) GS	0	-5	0	not relevant	0	not relevant	not relevant	not relevant

***GS, in growing season**

For killing frost a distinction was made between winter frost (when the plant is dormant) and spring frost, when the growing season has started. Frost occurrence in this early growth stage can be particularly harmful for some crops (see Table 16) such as cardoon, giant reed and eucalyptus limiting the area in Europe they can grow significantly as compared to switchgrass and also miscanthus. The latter crop is however not able to cope with too extreme winter colds as it limits strongly the survival rate and prevent enough re-growth in spring. This explains a slightly smaller area suitability coverage for miscanthus as compared to switchgrass or willow.

The temperature range indicator in Table 15 shows the minimum and maximum temperatures a crop has to cope with in the growing season. A small difference in temperature such as in the first 3 classes in Table 16 is typical the Boreal and Alpine north zones of northern Europe where growing seasons are very short and temperatures usually do not come far above 10 °C. In these regions it is not really worthwhile to grow biomass crops as yields will remain very low and most of the perennials cannot reach their minimal growing degree days to deliver good quality biomass.

Simulation of crop yields for the whole of Europe

Crop yield simulation model description

For miscanthus, switchgrass, giant reed, reed canary grass, cardoon and SRC willow, poplar and eucalyptus a simple crop simulation model was developed. To assess the yield of the biomass crops the data on daily weather factors (are combined in this model with the phenological factors determining the crop growth of a specific biomass crop. These factors were derived from a wide range of projects and publications on field trial based assessments with lignocellulosic crops under a wide range of soil and climatic circumstances in Europe. For a summary overview of the main characteristics per crop see Appendix 1 Table 56).For an overview of the input for the crop simulation model see Figure 8 and the key phenological factors per crop in Appendix 1 (Table 49).

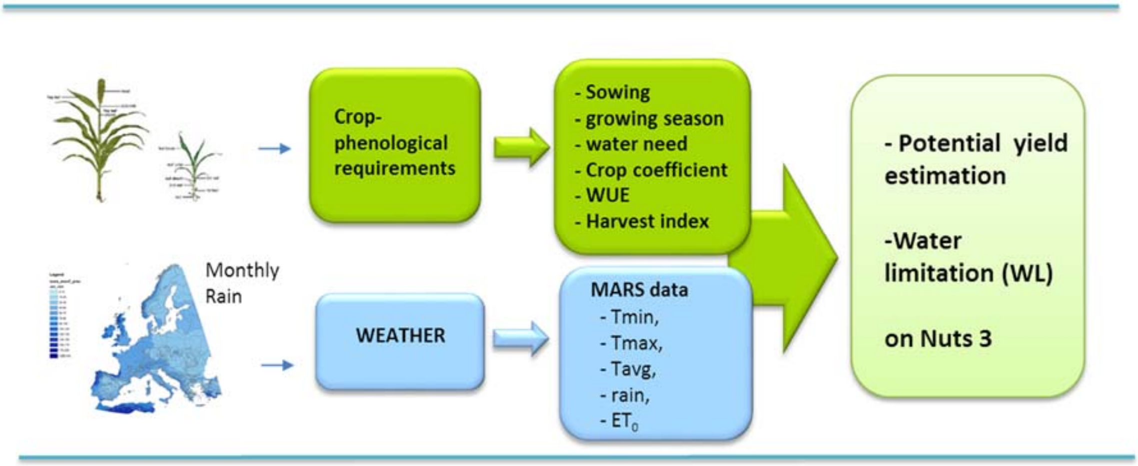


Figure 8 Diagram showing input and output of the crop simulation approach

Maintaining the original concept of a direct link between crop water use and crop yield, in this study we use the *AquaCrop* model evolved from the FAO (Equation Doorenbos and Kassam, 1979) as a base to development of estimation model for yield productivity.

$$B_{pot} = \Sigma ET0*Kc*WUE$$
$$B_{wl} = \Sigma ET0*Kc*F_{wl}*WUE$$
$$Y = B*HI$$

Where:

B_{pot} is the biomass Potential produced cumulatively (Mg ha^{-1}), *data for every Nuts3*

B_{wl} is the biomass in water limitation produced cumulatively (Mg ha^{-1}), *data for every Nuts3*

ET0 is the daily evapotranspiration for reference crop, with the summation over the time period in which the biomass is produced in growing season (either mm or m^3 per unit surface), *data for every Nuts3*

Kc Crop coefficient by calculating for each growth stage (*assumed constant value*)

WUE is the water productivity parameter or water use efficiency (either kg of biomass per m^2 and per mm, or kg of biomass per m^3 of water transpired), (*assumed constant value*)

HI is the Harvest index. Ratio of yield to biomass (%), (*assumed constant value*)

F_{wl} reduction factor to water limitation (%) in C3 and C4 photosynthetic system, for every Nuts2-3

Y Yield potential (Mg ha^{-1}), data *for every Nuts3*

For all crops, only part of the biomass produced is partitioned to the harvested biomass parts to give yield (**Y**) and the below ground plant part. The net useful biomass is found by multiplying the total biomass with the *Harvest Index* (HI).

To assess the yield of the biomass crops, the data on daily weather factors are combined in this model with the phenological factors determining the crop growth of a specific biomass crop (see Appendix 1, Table 56 & 57). These factors were derived from a wide range of projects and publications on field trial based assessments with lignocellulosic crops under a wide range of soil and climatic circumstances in Europe. For an overview of the main references used see also Table 58 in Appendix 1.

Input data for crop yield simulation

The estimation of crop production level for each crop and all regions depends on the availability of data on crop, weather, climate, soil and farm management. Further, it is very important to have data on real yield estimates (from real field trials) in as many European regions possible to validate the result of the yield simulation (See Appendix 1, Table 50).

The study area is Europe and neighbouring countries, and includes EU28, the Balkan countries, Moldova, Turkey and Ukraine.

- Et0 daily evapotranspiration for reference crop (Penman – Monteith method[5])

Crop parameters

Crop parameters have been collected from literature for a number of annual and perennial biomass crops: miscanthus, switchgrass, giant reed, reed canary grass (RCG), cardoon and woody Short Rotation Coppice (SRC) willow, poplar and eucalyptus.

The parameters are needed for the estimation of the start-date and length of the growing season, and the total water use and associated crop biomass production. e.g. total length growing season (Lgs), minimum start day, growing degree day (GDD), minimum temperature above the which the crop becomes active, water requirement, crop coefficient (Kc), water use efficiency (WUE). For a summary overview of the crop parameters used see Appendix 1 (Table 57).

In addition, parameters are needed for the estimation of the crop water transpiration during the growing season. The growing season is divided into four Crop coefficient “Kc” phases (initial, crop development, midseason & late season) with specific crop water requirements for each kc phase. They are defined as fraction of length of

[5] **Reference evapotranspiration (ET0)** for every location in Europe was determined from the Penman-Monteith equation recommended by FAO.

season (total number of days). Each Kc phase is defined by its duration (in days-fraction) since the start of the phase.

Once the total evapotranspiration of a crop during the growing season has been calculated, the gross aboveground production (dry biomass) can be calculated with the Water Use Efficiency expressed in gram dry biomass per litre water. The net useful biomass is found by multiplying the total biomass with the harvest index (HI). Pot Yield = ΣETcseason* WUE * HI. Some parameters are not strictly needed, but serve as reference value. An overview of the crop parameter values is shown underneath and data are also provided per crop in the Tables in Appendix 1.

Meteorological data source

The meteorological data were harvested from the JRC-MARS database by the European Commission-Joint Research Centre (JRC). The daily long-term data (since 1975) were used the following variables: temperature minimum, average, maximum (°C), rainfall (mm) and reference evapotranspiration - ET0 (mm). The interpolated data are available on grid cells of 25x25 km. The land surface of the study area is covered by 8075 grid cells.

Yield Simulation

For every crop two simulations are made (at Nuts3 region level):

- The *maximum yield,* is simulated assuming no limits on water and nutrients.
- The *water limited yield,* is simulated assuming that water availability is limited by the precipitation (and related crop transpiration).

These yield simulations are input to the cost Model (described in next Section 2.3.3) to assess the Net Present Value (NPV) cost for dedicated crops. But before these yield simulation results are input into the cost calculation model they are first converted in a post-model processing into three types of yield-input-management levels: high, medium and low input:

- *Low (L),* no irrigation is applied. The yield level is dictated by water limited conditions (the lowest value of either 80% of the calculated water limited potential, or 50% of the full potential).
- *Medium (M),* no irrigation is applied, with the exception of the establishment phase for some dedicated crops. The yield level is the lowest value of either the water limited potential or 90% of the full potential.
- *High (H),* irrigation is applied. The yield level is set to 90% of the full potential.

Calculation of the net present value cost level for perennial crops

Within S2BIOM an activity based cost (ABC) model was developed to calculate the net present value cost of different types of biomass crops. This model and the approach to assessing the NPV cost for dedicated crops is described in next Section 2.3.3.

Integration of CAPRI land availability, crop suitability layers, yield and NPV cost levels results for assessment of the dedicated biomass for different potential options.

In this last step the biomass potential calculation is made. This is done as follows:

1. Determine for the CAPRI dedicated cropping locations given RED limitations:
    a. What mix of biomass crops is suitable
    b. Identify for the location which yield level is attainable according to crop yield simulation, bio-physical suitability factors and match to the management systems possible (high, medium and low input systems)
2. Identify per location the top 3 crop-management combinations generating the average Net Present Value cost (€/ton d.m.). How the cost are calculated for dedicated cropping is described in the next section 2.3.3
3. Match the CAPRI and RED constrained locations with the attainable yield levels of the top 3 crops and calculate the total biomass production potential per nuts 3 region assuming an even land distribution over the different suitable crops.
4. Generate biomass potential maps for dedicated cropping potential total and per type of biomass crop.

2.3.3 Methods to estimate costs

Detailed information about the biomass potential of different crops in different locations is of eminent importance within the S2Biom project. The ABC model developed in S2BIOM to assess the road side Net Present Value (NPV) Cost of agricultural biomass from residues and dedicated cropping has already been explained in general terms in Chapter 1 and also in more detail for the calculation of cost of primary residues (Section 2.2.4). In this Section the calculation of the road side NPV cost for dedicated biomass crops is described, which involves the most extensive calculation of cost with the ABC model.

In order to assess the cost of a dedicated crop per location in Europe, 8 interrelated excel work sheets in the ABC model need to be filled. This enables calculation of dedicated biomass Net Present (NPV) cost per type of crop, in a 60 year cycle for every Nuts 3 region in Europe for 3 management systems: low, medium and high input management systems. The low input systems are tuned with low productive soils in more marginal conditions, while the high input systems are tuned with higher quality soils where input limitations are expected to be more limited because higher yields are possible.

Plantation life time per crop type assumed is as follows:

- 12 years for SRC willow, poplar and eucalyptus and cardoon.
- 15 years for perennial grasses

In Figure 9 an overview of the model is presented. The model is designed to calculate the cost of cropped biomass according to crop yield simulation levels and related irrigation water use requirements as assessed per Nuts 3 region in Europe with the AquaCrop model as explained in Section 2.3.2 of this report.

So to run the model the case inputs need to be specified in the '**Case input**' module which include the type of crop, the yield level (from the crop yield simulation) and related irrigation need and management. The yield and related (irrigation) water requirements per region in Europe are the output from the crop yield simulation model (as described in Section 2.3.2). As to the crop selection, the cost model is run for all 3 dedicated crops & management system combinations in every region of Europe. These three yield levels are adapted from the two extreme yield levels simulated in the crop growth model which are the water limited yield and the maximum yield assuming no water nor nutrient deficit in any growing phase of the crop:

- **Low (L):** no irrigation is applied. The yield level is dictated by water limited conditions (the lowest value of either 80% of the calculated water limited potential, or 50% of the full potential)
- **Medium (M)**: no irrigation is applied, with the exception of the establishment phase for some dedicated crops. The yield level is the lowest value of either the water limited potential or 90% of the full potential
- **High (H)**: irrigation is applied. The yield level is set to 90% of the full potential

Irrigation is thus only applied in the High yield management combination and never occurs in the Low and Medium.

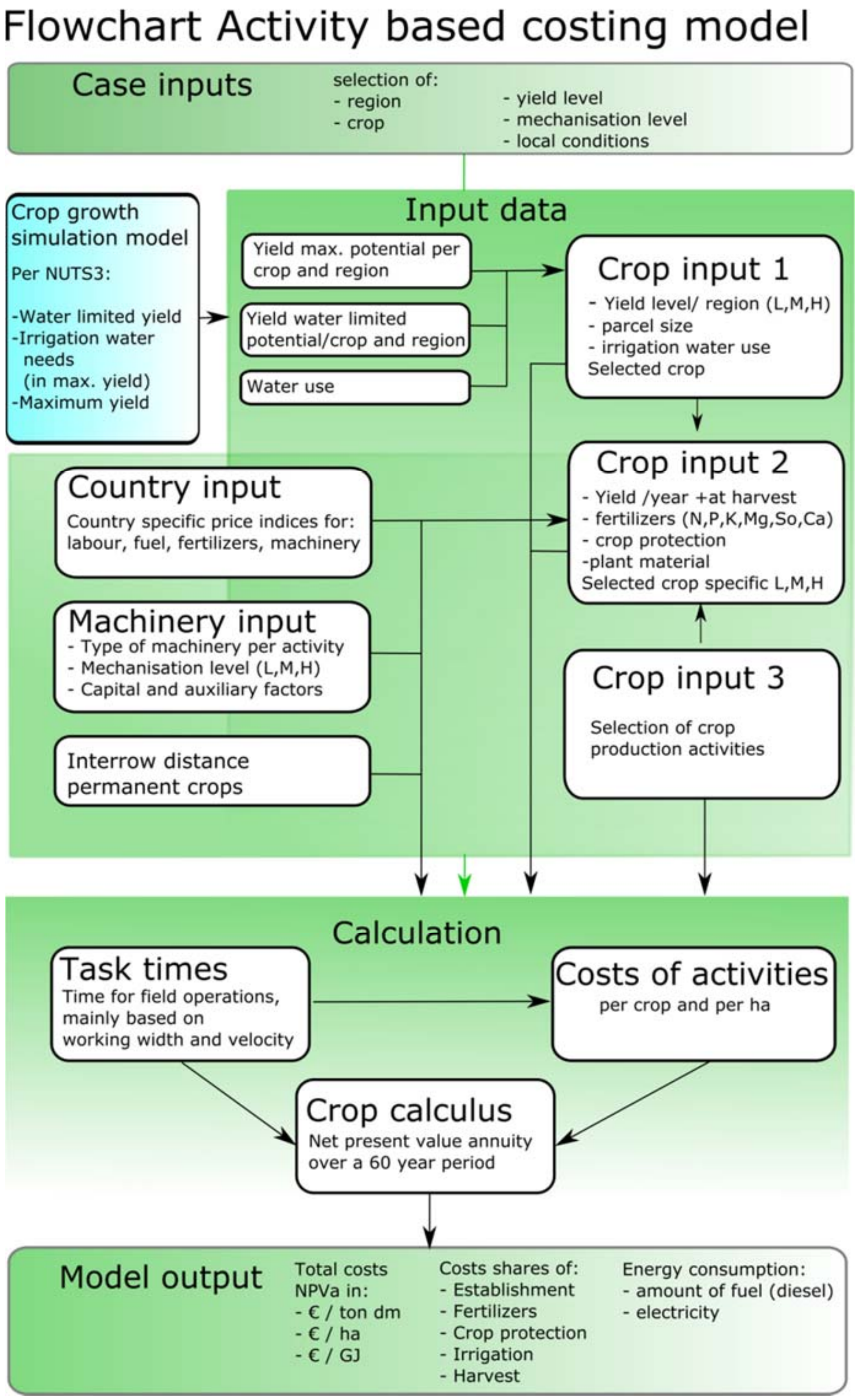


Figure 9 Overview of ABC cost calculation model for dedicated biomass crops

The last item to select is the management level, which can also be low, medium and high input. The most efficient level, generating the lowest cost, is an outcome of the yield level and the management level combination chosen. The costs associated with the degree of mechanization are particularly sensitive to the field size (parcel size), especially where field sizes drop below 4 – 6 ha. Information was therefore derived on average parcel size for different crops at nuts 3 level from the Lucas database[6]. For every region an average field size was generated and used as input into the calculation of cost for the specific region.

Once the case inputs have been specified, the three crop input sheets are filled accordingly.

Crop inputs 1 module sheet gathers the potential yield level of the selected crop and water use combination at national or nuts3 level from the crop yield simulation model for dedicated crops as discussed in the former (Section 2.3.2). In this sheet the crop yield and water application levels are also specified for every year in the 60 year cycle the NPV cost levels need to be calculated for. Therefore, it takes account of a harvest cycle specific to every crop. Furthermore, the worksheet contains a table with information about the average parcel size for different crops at nuts 3 level estimated from the Lucas database (see above). As a reference the parcel size of the land cover category 'fallow land' was selected because this land category is making up part of the released land resource potentially converted to dedicated crops in the near future. Furthermore, it is a land class covered sufficiently well in the LUCAS database.

The sheet '**Crop inputs 1**' passes the information on to **Crop inputs 2** module**.** This sheet then gathers the condensed information of the selected crop covering information on inputs specific to the yield type, yield level and input level selected in the case input sheet. It includes the following:

- irrigation need m3/ha (from the selection in crop inputs 1) specific per yield-management combination (so only applied in High input systems)
- plant material input value in seed or rhizomes expressed in €/ha, based on expert knowledge and –judgement for each crop. For distribution over management systems we assume that these cost are at 100% for Medium input systems, for Low it set to 90% and for High it is set to 110%.
- crop protection inputs for insecticides, fungicides herbicides and growth regulators in €/ha per treatment (this information is derived from the S2Biom crop management database for perennial biomass crops, see Section 2.2). For distribution over management systems we assume that these cost are at 100% for Medium input systems, for Low it set to 50% and for High it is set to 150%.
- fertilizers in €/ha. The value is calculated in the sheet using information on the nutrient content specific for the selected crop (N,P_2O_5,K_2O,MgO,S, CaO) which is also included in this sheet for every crop. These nutrient content levels have been collected in S2BIOM in the database with biomass characteristics which is described in Deliverable 2.1. However, since price

[6] LUCAS database, 2013, Eurostat (http://ec.europa.eu/eurostat/statistical-atlas/gis/viewer/?myConfig=LUCAS-2012.xml). LUCAS data used are from the LUCAS 2012 Survey. It provides a distribution of agricultural Corine land cover classes (e.g. arable, permanent crops, olives etc.) over 4 parcel classes: <0.5 ha, 0.5-1 ha, 1-10 ha and > 10 ha.

information is not gathered for MgO, S and CaO, these nutrients are not operational in the present version of the model. SFertilization application rates are equal to this removal rate plus an extra 33% application for losses of nutrients. Fertilization application rates at establishment of the crop are also included separately and are derived from the S2Biom crop management database for perennial biomass crops (see Section 2.2). The fertilizer costs take account of the application level needs per crops are explained but also of national specific price levels for fertilizers. The national price levels are included in the '**National inputs**' data sheet of the model explained later.

In the module **Crop inputs 3** the different crop management activities are gathered according to the crop management selection in the case input. In order to make crops with different cropping intervals comparable through time, activities are set on or off per year over a 60 year cycle. With a total cycle of 60 years complete cycles of 1,2,3,5,10,12,15,20 or even 30 and 60 year intervals can be covered by the model. In the first rows 10 different patterns of activities are pre-designed ranging from one activity every year, or 3 times a year or every 3 years etc. (see Appendix 3, Table 58). In the second part of the sheet all possible activities that can be performed are specified and information on the frequency of the performance of this activity per crop is specified by allocating one of the frequency patterns available above (see Appendix 3, Table 58). Separate blocks are reserved to set the activities in the starting year as well as the number of activities of a kind in one year.

In the **'Country inputs'** module detailed information concerning the prices of various resources needed as input for the production process of biomass are gathered specific per country. These are specified either in absolute price levels or as an index related to the known price level in one or two specific countries (mostly Germany). This is necessary as prices of key production factors differ a lot at national level across Europe. National level price data (ex. VAT) included cover cost/prices for labour (skilled, unskilled and average), fuel, electricity, fertilizers (N, P2O5, K2), machinery, water, crop protection and land. Most of these data were gathered from statistical sources such as FADN (Farm Accountancy Data Network), Eurostat and OECD. Most cost levels were gathered for the year 2012.

The '**Machinery inputs**' module contains extensive information about different aspects of mechanized equipment involved in field operations. In practice all kinds of equipment exists even for a single crop. Because of this and also because of a lack of data about the actual deployment of this equipment at regional level an average machine input mix was chosen belonging to every activity but specified per management level. So larger machines are generally used in High input systems if these can be operated on the average field sizes encountered in the region under focus. The average field sizes as collected in LUCAS and gathered in the sheet Crop Inputs 1 are guiding in mechanization possibilities. The main source of information used to gather all financial and functional characteristics of the different machines is the German online database "KTBL-online". It entails an extensive range of equipment and a similar database is available at WUR (KWIN). Low, medium and high machinery input alternatives from this list have been chosen as typical instances. The following aspects are handled (See also Appendix 3):

- Capacity; the equipment is classified as Low, Medium or High capacity
- Capacity in tonnes (Apt), gives the amount of production per transport operation
- Effective working width in m (We)
- Operating velocity in km/h (V)
- Replacement value in €
- Technical lifetime in years
- Rest value in € (default value is set to 1)
- Average annual costs as a percentage of the replacement value is the sum of:
    - Depreciation rate (%)
    - Interest rate (%)
    - Auxiliary (%) For maintenance & repair, storage, insurance
- Potential use per year (hr) or in case of some parts of the irrigation system per ha. The value is often based on expert judgement, considering the technical lifetime as well as usability during the season.
- Machine cost per hour in €. Calculated from the average annual costs and potential use
- The number of machines involved in a field operation. The default is set to 1
- Energy, Fuel & lubricant costs / hr (€):
    - Traction fuel (l/hr). Only set when traction is involved, i.e. tractors and self-propelled machines
    - Traction oil (l/hr). see fuel
    - Fuel price (€/l). A default value is set
    - Oil price (€/l). A default value is set
    - Electricity (kWh)
    - Electricity price (€/kWh)
- Country correction with indices from the worksheet '**Country inputs'** are taken to adapt the above cost levels to the national level

In the '**Task Time Activity'** module for a number of activities (field – operations) the amount of time needed to fulfil the operation is calculated with a model from De Lint et al (1970) recognizing the following parameters:

* PLFp .... Pure labour time for field activities per parcel in hours
* a .... contstant time per ha in hours = (a1 for standard field operations; a2 for loading or unloading storage containers; a3 for waiting time in case of changing transport means)
* b ....time in hours per 100m parcel width
* Wp .... Width of parcel in 100m
* Lp .... Lenght of parcel in 100m
* wc .... constant share of the time per 100m width of parcel remainder in hours, that is approcimately (100/ We).(Etr/60)
* Wpp .... Width of parts of the parcel to be worked at on the parcel remainder in m
* wv .... variable part of time per 100m width of the parcel remainder in hours per 10m width of wpp
* Wrp .... Width of the parcel remainder in 100m (Wrp = Wp -2.Hw)
* c .... time in hours per 100m lenght of parcel
* d .... contant time in hours per parcel (corners) = 2*Hw/We*(Etr/60)*Fh
* RT .... resting time (surcharge) in %
* We .... Effective operating width
* V .... Operating velocity in km/h
* Hw .... Headland width in 100m
* Etr .... Time attributed to operations per round expressed in minutes for the parcel remainder
* dV .... Decrease in operating velocity in % of V
* Fh .... Factor for the number of operations on headland (1 for seperate operation on headland; 2 if not)
* Fr .... Factor to calculate wv out of wc (the literature is not unambiguous at this point, but it is not of great importance either, so we estimated based on tables of De Lint et al (1970)
* MT .... Technical malfunction time
* TL ....Time for loading/ unloading activities in minutes per operation
* RRp .... Time for running-in / -out in hours per parcel (for cleaning equipment etc)
* RRhdc .... Time for running-in / -out, constant part in hours per shift
* e .... Time for on parcel movements in hours per shift
* f .... Time for on road movements in hours per km
* NP .... Number of persons
* NHD .... Rounded number of halve days (break time standard at 4 hours shift) for the operation
* NVha..........Number of volume/ container units per ha (APha / APc)
* NTha .... Number of transports per ha (affects ETr ; = APha / APt)
* ETt .... Time per transport in min
* Vt ....Velocity road transport
* Pla .... Plot distance in km
* APha .... Amount of production in t dm /ha
* APt .... Amount of production per transport in t dm
* APc .... Capacity of container in mt
* Pha .... Parcel surface area in ha
* fa........factor for working routes (0= seperate operation on headland; 1= headland not seperated)
* f_a1 .....a1 on=1, off=0
* f_a2 .....a2 on=1, off=0
* f_a3 .....a3 on=1, off=0
* running in time
* TT .... Time consumed by the Task

We assume:
the remainder of the parcel is treated once, i.e. Wpp = Wrp
Width of the headland equals the effective width of machinery in case this is >10m, i.e. Hw-We/100 or 10

The actual time consumed by a task is calculated with the following formula:

Formula for calculation of task times (per activity)
Background
The formulas can be applied to various working routes (see image)
Calculation of the (pure) task time per parcel:
fieldwork at constant speed
loading / onloading activities
transportation activities

PLFp=a.Wp.Lp+b.(Wrp.fa)+c.Lp+d (1)
a=a1+a2+a3 (2)
a1= (100+RT)/(10.We.V) (2a)
a2 = APha/APc*(TL/60)*(100+RT)/100 (2b)
a3= NTha*(ETt/60)*(100+RT)/100 (2c)
b=(wc+(Wpp/10.wv) (3)
wc= (100/ We).(Etr/60) (4)
Wrp=(Wp-2.Hw) (5)
c=b (6)
d=2*Hw/We*(Etr/60)*Fh (7)

TTha= ((PLFp.(100+MT)/100+RRp+NHD*(RRhdc+e.Wp+f.Pla))/Pha)*NP (8)
NHD=(PLFp.(100+MT)/100+RRp/(4-NHD???*(RRhdc+e.Wp+f.Pla)) (9)
e=1/(5*V) (10)
f=2/Vt (11)

Task times are calculated for the following activities:

treat_A= clear field/stubble cultivation
treat_B= ploughing
treat_C= disking
treat_D= cultivating
treat_E= pressing & rolling
treat_F= one pass tillage train
treat_G= cereal drilling/ power harrowing combi
treat_H= planting
treat_I= sowing
treat_J= transport
treat_K= manure applicatiom
treat_L= fertilizer application
treat_M= weed control
treat_N1= irrigation setting up/ installation
treat_N2= irrigation automatic operation
treat_O= thinning
treat_P= harvesting (beet)
treat_Q= cutting
treat_R= combining
treat_S= mowing
treat_T= mulching
treat_U= turning/ raking
treat_V= baling of wheat straw
treat_W= loading/ transport/stacking of wheat straw
treat_X= transport headland - depot wheat straw
treat_Y= storage (wheat straw)

All modules described in the former then transfer the parameters to the **Calculus** module. This module consists of 2 calculation sheets which are linked. The first is the '**Activity cost calculus'**. In this module all activities cost are gathered from the different input sheets to calculate the total cost of all activities involved in terms of machinery, labour input and energy input requirements.

The time consumption per activity is gathered from the '**Task Time Activity'** module as discussed above. An example for the calculation of total cost is given in Table 17 for soil preparation and sowing activities.

The final calculation worksheet which generates the final cost is the '**Crop calculus'** module. In this final worksheet all the costs associated with the selected crop in the specified region are expressed in a net present annuity, making each crop comparable through time. It adds up for the specific case input selection all activity cost, and all input cost per year, for the total lifetime of the plantation and repeats this until it reaches a total of 60 years. Then the Net Present Value annuity is applied assuming that the sum of NPVs cover the annual capital payments attracted against the same interest rate (4%) as the discount rate used for calculating the NPVs.

Table 17 Example of cost calculation for soil preparation and sowing activities

Activities			labour				machinery						
level 1	level 2	level	cost calculation	unit	category (skilled / unskilled)	total labour (country corrected) €/ha	cost calculation	unit	machine tarif	unit	total machinery €/ha	total annual cost activity €/ha	fuel consump-tion l/ha
soil preparation													
	cleaning field (removal of roots and shrubs)	L	1.4	hr/ha	S	3.8	1.4	hr/ha	18.9	€/hr	27.3	31.1	9.2
	ploughing	L	2.3	hr/ha	S	5.9	2.3	hr/ha	15.7	€/hr	35.8	41.8	14.5
	disking / harrowing/ rotavating	L	1.0	hr/ha	S	2.5	1.0	hr/ha	15.7	€/hr	15.2	17.7	6.2
	pressing / rolling	L	0.7	hr/ha	S	1.8	0.7	hr/ha	14.8	€/hr	10.3	12.1	4.4
								hr/ha		€/hr			
soil preparation + sowing combi	cereal drilling/ power harrowing combi	L	0.6	hr/ha	S	1.6	0.6	hr/ha	27.6	€/hr	17.3	18.9	4.0
sowing								hr/ha		€/hr			
	planting	L	9.0	hr/ha	S	23.4	4.5	hr/ha	14.9	€/hr	67.3	90.7	28.7
	sowing	L	0.6	hr/ha	S	1.6	0.6	hr/ha	17.9	€/hr	11.2	12.8	4.0
		L		hr/ha	S			hr/ha		€/hr			
	transport headland - depot	L	0.2	hr/ha	S	0.5	0.2	hr/ha	14.1	€/hr	2.6	3.1	1.2

The total sum of NPVs over all 60 years can then be divided by the biomass harvested to express the NPV value in €/ton dm. By multiplying this with the energy contents (lower heating value, LhV) a conversion to GJ is made to come to the cost expressed in €/GJ. The final NPV cost are presented in sub-categories of cost as shown underneath.

Output (NPVa €/ton dm)
Fertilisation cost
Crop protection cost
Irrigation cost
Harvest cost
Total cost

2.4 Unused agricultural grassland cuttings

2.4.1 Potential categories and potential types

The grassland cuttings potential assessed refers to biomass derived from grasslands that are part of the farming area. The land delivering the biomass is still in the agricultural land base as statistically reported. The land that provides this biomass resource is not abandoned officially, but is likely not to be exploited for feed production.

Table 18 Subcategories of second level category “23 Grassland”

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
231	Grassland	2311	Unused grassland cuttings (abandoned grassland, managed grasslands not used for feed)

Only one type of potential is assessed for this biomass type which is the maximum amount of grassland cuttings that can be derived from grasslands not used for livestock feed. This implies that the Technical potential = Base potential.

Table 19 Overview of unused agricultural grassland biomass potential types and considerations

	Area/ Basis	Yield, Growth	Technical & environmental constraints on the biomass retrieval (per area)	Consideration of competing use	Mobilisation
Technical (unused grassland)	Area in 2012, 2020, 2030 with permanent grassland & rough grazing	Growth based on average national yields (Eurostat) and yield levels per environmental zone (Smit et al, 2008) growing conditions & management. Yield according to regional averages including expected developments in yield towards 2020 and 2030 (as in CAPRI)	Maximum volume of grassland cuttings	Use for animal feed according to feed balance (Hou et al, 2016)	None
Base (unused grassland)	Same as in technical potential	Same as in technical potential	Same as in technical potential	Same as in technical potential	Same as in technical potential

2.4.2 Methods to estimate the supply potential

The potential calculation was done using the MITERRA-Europe model (Velthof et al., 2009; Lesschen et al., 2011; de Wit et al., 2014) and builds on two main assessments. The core of the analysis is the calculation of a feed balance at regional level covering the total grass use for feed in every region. This approach is described in Hou et al. (2016) and is the basis for the assessment of the nitrogen excretion of livestock in the EU-27 at regional level (Nuts 2). In this assessment, the total grass production is based on grassland yields of Smit et al. (2008) and grassland areas based on 2010 Eurostat data both at NUTS2 level.

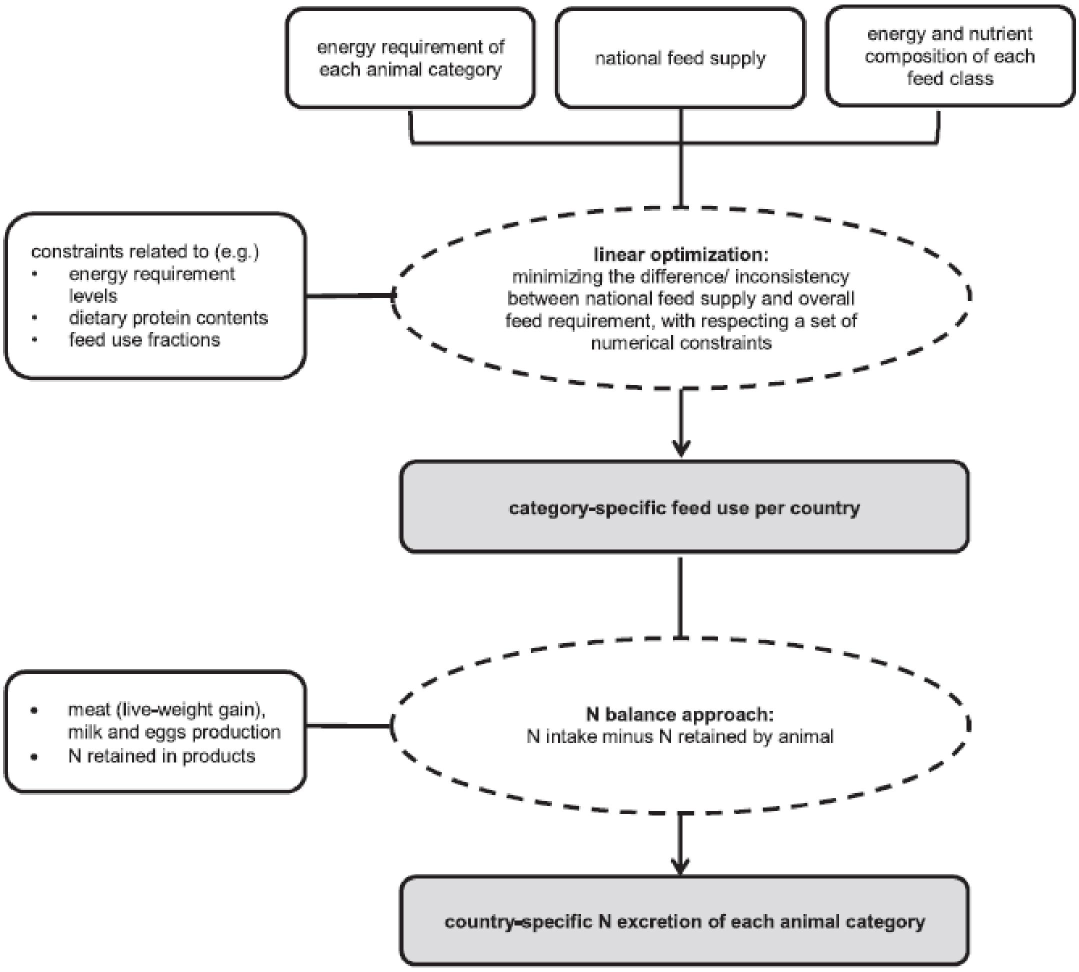


Figure 9 A simplified schematic representation of the information flow in calculating country-specific feed use and nitrogen (N) excretion of each animal category from Hou et al. (2016).

In Figure 9 a schematic overview is given of how the feed balance is calculated to generate livestock category specific feed use per country which goes into the nitrogen balance to arrive eventually at country-specific N-excretion of each animal category. The national feed supply and compositions were derived for eight aggregated feed classes:

(i) animal and fish derived feed,
(ii) protein-rich feed (e.g., soybean meal),
(iii) cereal (grain or processed) feed,
(iv) brans,
(v) oil and sugar crops,
(vi) other non-roughage feed (e.g., root crops, and residues of fruits and vegetables),
(vii) annual forages (e.g., maize silage, leguminous crops, temporary grass, and crop straw)
(viii) perennial forages (grass harvested by grazing and grass harvested for silage and hay).

The eight feed classes totals were then partitioned over animal categories using a linear optimization approach, taking account of category-specific (numerical) constraints related to energy and protein requirements, with the objective of minimizing the difference between the total feed biomass supply and the total feed biomass requirements per country. The following assumptions were made (see also Hou et al.,2016):

1) The energy requirement per animal category for 'average' conditions per country was taken (e.g., average climate, animal genetics and animal performance).
2) The average crude protein (CP) contents of the animal diets were constrained by a set of category-specific ranges derived from literature (e.g., Bittman et al., 2014).
3) Roughage (grass, forages and crop residues) were allocated to ruminants, cereals and protein-rich feeds were offered mainly to poultry and pigs.
4) All animals in one country use at least 85% of the supply of high-quality feed classes, such as protein-rich feed and feed cereals, and at least 70% of the total supply of animal and fish derived feed, brans, root and sugar crops and grass from managed grassland. For the assessment of unused grass-cuttings here it is important to know that it was assumed that the minimum percentages of feed use for annual forages were set at 40% of the supply. The other non-roughage feeds (e.g., root crops, residues of fruits and vegetables) were set at 20% at the minimal and natural grass ('rough grazing' in statistics) at only 10% and crop residues at 10%. In this way it was guaranteed that animals make full use of the high-quality feeds. Feedstuffs from crop residues are known to be insignificant in animal diets (in most EU countries), thus low priority for their use were assumed by using a low minimum percentage.

Data on the national supply of feed resources (except for grass, forages and crop residues) were extracted from FAO commodity balance sheets; data were corrected for export and import (FAOSTAT, 2014). The fresh or air-dry weights in the FAOSTAT database were corrected for moisture content to obtain a uniform dry matter (DM) weight of each feed item. The use of straw as feedstuff was based on domestic cereal production, the mean straw/grain ratio (Krausmann et al., 2008) and the proportion of crop straw recovered as feed (Krausmann et al., 2008). The supplies of grass and annual forages were estimated from the land areas of grassland and forages (Eurostat, 2014), multiplied by the regional productivity data of forages (Eurostat, 2014) and grass (Smit et al., 2008).

For the calculation of the unused grassland resource potential the total of Hou et al. (2016) 'perennial forages (= *grass harvested by grazing and grass harvested for silage and hay*)' was used. This total was then subtracted from the 'total biomass production from perennial forages' to come to a net unused grassland biomass availability. So the following formula was applied:

Unused grassland yield = (perennial forage croparea * yield * DM_content) – (perennial forage intake by animals).

Where:

- Perennial forage area: derived from CAPRI per country for 2012, 2020 and 2030
- Yield levels: derived from Eurostat (2014) and Smit et al. (2008)
- Dry matter (DM) content is:
    - Managed grass: 20%
    - Natural grass/rough grazing land: 20%

An important constraint of this approach is that it could only be applied to EU-27 countries (so excluding Croatia, western Balkans, Ukraine, Turkey and Moldova) and that it could only be assessed for 2012. Extrapolation of the methodology to the other non-EU countries was not possible given data limitations and time constraints to extend the MITERRA-Europe Europe model application. The same applied to the calculation for 2020 and 2030. Unsufficient data were available on the feeding balance in the future 2020 and 2030. So for EU-27 we assumed that the potentials for unused grassland cuttings remains stable. This however is a very rough assumption.

2.4.3 Method to estimate cost of grassland cuttings

Also for the calculation of road side cost of unused grassland cuttings the ABC model is applied. For the most detailed explanation of the model and all the different modules it consists of we refer to the description under 2.3.3 in the former.

The cost allocated to unused grassland cuttings consist of:

1) Mowing
2) Racking which is needed to dry the cuttings before baling
3) Baling
4) Collection and loading at the road side

All activities require calculations in the modules **Crop inputs 1,2 and 3, Country inputs, Task time, Costs of Activities** and **crop calculus**. In comparison to the calculation of dedicated cropping cost, the number of activities allocated to unused grassland cutting are much lower. They only include the activities of cutting, baling and collecting the grass to road side (or farm gate). Although unused grassland needs to be fertilized occasionally this activity is not included because of unknown, but assumed relatively large time intervals which would make the influence on the outcome marginal anyway.

The establishment of the grassland as a crop is not allocated either, because it can be assumed that the grassland is already there and that the establishment was done under the assumption to use it for livestock grazing or cutting for feed. However, in time the feed balance of the farm changed and the grassland remained unused. To keep it in good farming condition, as prescribed by the CAP, mowing/cutting remains necessary.

2.5 Wood production and primary residues from forests

2.5.1 Potential categories and potential types

General approach

The potential supply of woody biomass was estimated for the period from 2012 to 2030 for stemwood; branches and harvest losses (further: 'logging residues'); and stumps and coarse roots (further: 'stumps') (Table 20). First, we estimated the theoretical potential of forest biomass supply in Europe based on detailed forest inventory data. This theoretical potential was defined as the overall, maximum amount of forest biomass that could be harvested annually within fundamental bio-physical limits (adapted from Vis and Dees 2011, Dees et al. 2012), taking into account increment, the age-structure and stocking level of the forests. Second, multiple environmental and technical constraints were defined and quantified that reduce the amount of biomass that can be extracted from forests for different biomass potential types. Third, the theoretical potentials from the first step were combined with the constraints for the biomass potential types.

Table 20 Subcategories of first level category 1 "Forestry"

Second level subcategories		**Third level subcategories**		**Final level subcategories**	
ID	Name	ID	Name	ID	Name
11	Production from forests	111	Stemwood from final fellings &thinnings	1111	Stemwood from final fellings originating from nonconifer trees
				1112	Stemwood from final fellings originating from conifer trees
				1113	Stemwood from thinnings originating from nonconifer trees
				1114	Stemwood from thinnings originating from conifer trees
12	Primary residues from forests	121	Logging residues from final fellings &thinnings	1211	Logging residues from final fellings from nonconifer trees
				1212	Logging residues from final fellings from conifer trees
				1213	Logging residues from thinnings from nonconifer trees
				1214	Logging residues from thinnings from conifer trees
		122	Stumps from final fellings	1221	Stumps from final fellings originating from nonconifer trees
				1222	Stumps from final fellings originating from conifer trees
				1223	Stumps from thinnings originating from nonconifer trees
				1224	Stumps from thinnings originating from conifer trees

This sequence of steps is based on the approach developed and applied within the EUwood and EFSOS II studies (Verkerk et al. 2011; UNECE et al. 2011; Verkerk 2015). The approach in S2BIOM differs from previous studies in several ways, with the main difference being that that woody biomass potentials have been estimated using a typology of potentials developed within S2BIOM. Other changes include (i) an updated of the forest inventory data used as a basis to estimate biomass potentials; (ii) extension of the geographical scope to include all 37 S2Biom countries; (iii) improvements to set the of constraints; and (iv) improve the potential estimates at regional level by spatially disaggregating estimated biomass potentials. All improvements are described below.

<u>S2BIOM biomass potential typology</u>

Within S2BIOM biomass potentials were estimated for the following types:

- The **Technical potential** represents the absolute maximum amount of lignocellulosic biomass potentially available for energy use assuming the absolute minimum of technical constraints.
- The **Base potential** can be defined as the potential most closely aligned to current guidelines of sustainable forest management. This also covers legal restrictions such as restrictions from management plans in protected areas, eg. Natura 2000.
- The **High potential** is a potential with less constraints compared to the base potential, assuming a strong focus on the use of wood for producing energy. It includes a strong mechanisation of harvesting across Europe. Biomass harvesting guidelines are less restrictive, e.g. stumps are included in this potential for all S2Biom countries.
- The **User-defined potentials** are derived from the Base Potential, but vary in terms of type and number of considerations per biomass assortment.
    a. User defined potentials 1-4 vary in consideration of environmental constraints, as compared to the Base potential.
    b. User defined potentials 5 and 7 allow the determination of the potential available for energy and new bio-based materials production. Wood production dedicated for material use is deducted and considered as a constraint.
    c. User defined potentials 6 and 8 allow the determination of the utilisation for pulp and paper, particle board, energy and new biobased materials production. In comparison with User defined potentials 5 and 7 wood dedicated for pulp and paper and for particle board production is not deducted as a constraint.

The Base and High Potentials include the constraints considered for the Technical Potential, but take additional constraints into account. The user defined potentials are variations of the base potential. The user defined potentials consist of four options. Each of these options allow the user to evaluate the effect of changes to protected forest area, harvesting practice, or technical and environmental constraints and to evaluate the potential availability of biomass under differing policy environments. All potentials are summarised in Table 21. The exact constraint values are based on interpretations of these potential types, as explained in section 4.3.2.

Table 21 Overview of woody biomass potential types used in S2BIOM

	Area/ Basis	Yield, Growth	Technical & environmental constraints on the biomass retrieval (per area)	Consideration of competing use	Mobili-sation
Technical	Forest area available for wood supply. This excludes protected and protective areas, where harvesting is not allowed according to protection purpose.	Growth based on regional to national growing conditions, including changes in biomass increment due to climate change. Yield according to regional management guidelines for age limits for thinnings and final fellings.	Maximum volume of stemwood that could be harvested annually during 50-year periods. Technical constraints on residue and stump extraction (recovery rate)	None	None
High	As for technical potential	As for technical potential	As for technical potential, but considering additional less stringent constraints (compared with base potential) for residue and stump extraction: Site productivity -Soil and water protection: ruggedness, soil depth, soil surface texture, soil compaction risk -Biodiversity (protected forest areas) -Soil bearing capacity.	None	None
Base	As for technical potential	As for technical potential	As for technical potential, but considering additional constraints for residue and stump extraction: -Site productivity -Soil and water protection: ruggedness, soil depth, soil surface texture, soil compaction risk -Biodiversity (protected forest areas) -Soil bearing capacity.	None	None
User potential - option 1	Reduction of FAWS by 5%	As for technical potential	Equivalent to increase of protected forest area by 5%.	None	None
User potential - option 2	Reduction of FAWS by 5%	As for technical potential	Increase of protected forest area by 5% and increase in retained trees by 5%.	None	Reduction in harvest by 5%
User potential - option 3	As for technical potential	As for technical potential	No stump extraction.	None	None
User	Reduction of	As for technical	Increase in protected	None	Reduction

	Area/ Basis	Yield, Growth	Technical & environmental constraints on the biomass retrieval (per area)	Consideration of competing use	Mobili-sation
potential - option 4	FAWS by 5%	potential	forest by 5% plus increase in retained trees by 5% plus no stump extraction		in potentials by 5%
User potential - option 5	As for base potential	As for base potential	As for base potential	Roundwood production for material use (aggregate of FAO Production categories: Sawlogs & Veneer Logs + Pulpwood, Round & Split + Other Industrial Roundwood) in period 2010-2014) subtracted from BP.	None
User potential - option 6	As for base potential	As for base potential	As for base potential	Roundwood production for material use excl. for pulp and paper and board industry (aggregate of FAO Production categories: Sawlogs & Veneer Logs + Other Industrial Roundwood) in period 2010-2014) subtracted from UP4.	None
User potential - option 7	As for user potential - option 4	As for user potential - option 4	As for user potential - option 4	Roundwood production for material use (aggregate of FAO Production categories: Sawlogs & Veneer Logs + Pulpwood, Round & Split + Other Industrial Roundwood) in period 2010-2014 subtracted from BP.	As for user potential - option 4
User potential - option 8	As for user potential - option 4	As for user potential - option 4	As for user potential - option 4	Roundwood production for material use excl. for pulp and paper and board industry (aggregate of FAO Production categories: Sawlogs & Veneer Logs + Other Industrial Roundwood in period 2010-2014) subtracted from UP4.	As for user potential - option 4

Units used:

- ton dry matter utilising the following conversion factors: Non Conifer 0.542 t/m3 Conifer 0.415 t/m3

All potential levels are provided for 2012, 2020 and 2030.

2.5.2 Methods to estimate the supply potential

The description of the methods to estimate woody biomass potentials from forests is heavily relying on the method that was developed and described by Verkerk et al. (2011).

Theoretical potential

Model description

We applied the large-scale European Forest Information SCENario model (EFISCEN) (Sallnäs, 1990) to assess the theoretical potential of forest biomass at regional to national level. We used versions 3.1.3 (Schelhaas et al. 2007) and 4.1 (Verkerk et al. 2016a). We used these two versions, because the former version is included in a script to estimated biomass potentials Verkerk et al. (2011), while the latter version has the ability to directly store results in a database, which is used to run the EFISCEN disaggregation tool (Verkerk et al. 2016b). EFISCEN describes the state of the forest as an area distribution over age- and volume-classes in matrices, based on data on the forest area available for wood supply (FAWS), average growing stock and net annual increment collected from NFIs. Forest development is determined by different natural processes (e.g. increment) and is influenced by human actions (e.g. management). A detailed model description is given by Schelhaas et al. (2007; 2016).

National forest inventory data on area, growing stock and net annual increment are used to initialize the EFISCEN model. NFI data was updated for 8 countries (Austria, Czech Republic, Finland, Germany, Ireland, Netherlands, Ukraine, United Kingdom) within the EFISCEN database Table 22.

Table 22 Overview of NFI data used in EFISCEN

NUTS0_ID	Country	Group	Inventory year
AT	Austria	EU28	2007-2009
BE	Belgium	EU28	1995-1999
BG	Bulgaria	EU28	2000
HR	Croatia	EU28	1995
CZ	Czech republic	EU28	2010
DK	Denmark	EU28	2000
EE	Estonia	EU28	1999-2001
FI	Finland	EU28	2004-2008
FR	France	EU28	1988–2000

DE	Germany	EU28	2012
HU	Hungary	EU28	2005
IE	Ireland	EU28	2012
IT	Italy	EU28	2005-2008
LV	Latvia	EU28	2004-2008
LT	Lithuania	EU28	2000
LU	Luxembourg	EU28	1989
NL	Netherlands	EU28	2012-2013
PL	Poland	EU28	1993
PT	Portugal	EU28	1997-1998
RO	Romania	EU28	1980s
SK	Slovakia	EU28	1994
SI	Slovenia	EU28	2000
ES	Spain	EU28	1986-1995
SE	Sweden	EU28	2004-2008
UK	United Kingdom	EU28	2012
AL	Albania	Other	1990
TR	Turkey	Other	2000
UA	Ukraine	Other	2011
MD	Moldova	Other	2000

In the model, the forest area was scaled to match the forest area available for wood supply (FAWS) as reported by Forest Europe (2015). FAWS are defined as "forests where any legal, economic, or specific environmental restrictions do not have a significant impact on the supply of wood" (MCPFE 2007). In this study the FAWS remains static until 2030 and effects of changes in forest area are not estimated. Future changes in forest area are uncertain and results from a previous study (Verkerk et al. 2011) indicated that continuation of the observed trends in forest area changes could lead to a rather small increase in biomass potentials, because in 2030 the new forests would still be rather young and only a limited amount of biomass can be extracted from these areas.

The amount of wood that can be felled in a time-step is controlled by a basic management regime that defines the period during which thinnings can take place and a minimum age for final harvest. Age-limits for thinnings and final fellings were based on conventional forest management according to handbooks at regional to national level (Nabuurs et al. 2007) and by consulting national correspondents (UNECE-FAO 2011). The amount of stemwood potential removed as logs was estimated by subtracting harvest losses from the stemwood felling potential. Harvest losses were estimated using the ratio between fellings and removals as reported by UNECE-FAO (2000) for coniferous and broadleaved species separately.

Branches together with harvest losses represent logging residues that can be potentially extracted as well. In addition, stumps could potentially be extracted, separately from logging residues. The volume of branches, stumps and coarse roots was estimated from stemwood volume (incl. harvest losses) using age-dependent, species-specific biomass distribution functions (Vilén et al., 2005; Romano et al., 2009; Mokany et al., 2006; Anderl et al. 2009). We assumed no difference in basic wood density between stems and other tree compartments, due to lack of information.

Climate change is accounted using results from LPJmL (Sitch et al. 2003, Bondeau et al. 2007). Data are an average for several climate models for the A1b SRES scenario. Annual tree Net Primary Production (NPP) in gC/m2 for 3 individual years (2010, 2020, 2030) was calculated with LPJmL and used to scale the increment functions used in EFISCEN.

Model simulations

For countries where inventory data was available from before 2010 (Table 22) the structure of the forest resources in 2010 was estimated by running EFISCEN until 2010, using historical roundwood production (FAOSTAT) converted to overbark volumes (assuming a bark fraction of 12%). The EFISCEN model was then used to iteratively assess the theoretical harvest potential of stemwood for the period 2010-2030 for every five-year time-step. This potential was estimated by first assessing the maximum volume of stemwood that could be harvested annually during 50-year periods (i.e. 2010-2060, 2015-2065, etc.). From this maximum harvest level an average (maximum) harvest level was calculated. EFISCEN was then rerun to check whether this harvest level was feasible in the time step for which the theoretical potential was estimated. If it was not feasible, the harvest level was reduced by 2.5% and it was checked again. The whole procedure was repeated for every time-step and provided direct estimations of the stemwood potentials, as well as the associated potential from logging residues and stumps, from thinning and final fellings separately.

Additional calculations

EFISCEN could not be applied to all countries within S2BIOM, due to absence of the required forest inventory data. Instead, woody biomass potentials for Cyprus, Greece, Montenegro, FYROM, Bosnia and Herzegovina, Kosovo and Serbia were estimated as described in the biomass handbook developed in BEE (Vis and Dees, 2011); this approach assumes that the theoretical stemwood harvest potential was based on the net annual increment corrected for harvesting losses. We used aggregated data on forest area and net annual increment from Forest Europe (2015) or – in case of missing data – on Forest Europe (2011). For Greece we used net annual increment as reported by Meliadis et al. 2010. Net annual increment was scaled to account for climate change, as done for all other countries (Sitch et al. 2003, Bondeau et al. 2007). We used biomass allocation functions from Teobaldelli et al. (2009) and estimated stump biomass based on data by Asikainen et al. (2008). No data were available for Malta.

Constraints

Quantifying constraints

Constraint on biomass supply have been identified by Verkerk et al. (2011) and are reported in Table 22. Each of the constraints was quantified separately for the type of biomass (i.e. stemwood, logging residues, and stumps) and by type of felling activity (i.e. early thinning, thinnings and final felling) for the different biomass potential types. All assumption made to quantify the constraints for each potential type are shown in Appendix 2.

To avoid overlap, we applied a spatially explicit approach to quantify these environmental and technical constraints. We used spatial datasets on:

- site productivity, soil surface texture, soil depth and soil bearing capacity (EC 2006b)
- natural soil susceptibility to compaction (Houšková 2008)
- Natura 2000 sites (EC 2009b)
- fire weather index (average for summer months June, July, August over the period 1975-2005; Marco Moriondo, pers. comm.)

Previous studies (EUWood, EFSOS) included slope as a constraint on biomass supply. However, this constraint has limited meaning when working on a 1km grid level. Levers et al (2014) used the terrain ruggedness index (Riley et al 1999) to capture slope effects and found that it was an important predictor of forest harvest intensity as on the regional level. Hence, we used terrain ruggedness maps instead of slope maps to quantify the constraint. Riley et al (1999) define a terrain ruggedness index to quantify topographic heterogeneity, with the following classes:

- Level = 0-80m
- Nearly level = 81-116m
- Slightly rugged = 117-161m
- Intermediately rugged = 162-239m
- Moderately rugged = 240-497m
- Highly rugged = 498- 958m
- Extremely rugged = 959-4370m

We used the classes highly and extremely rugged to denote areas with steep slopes.

All spatial datasets were combined with the relevant constraint values for the different potential types. A raster layer was created for each constraint with a resolution of 1x1 km^2. Finally, all relevant layers were combined and the lowest, permitted extraction rate according to each potential type defined for each pixel.

Combining constraints with theoretical biomass potentials

EFISCEN is not a spatially explicit model. The level of detail in the input data determines also the level of detail of the output data. Consequently, EFISCEN estimates the future state of European forests, as well as the biomass availability at the level of administrative regions. However, these estimates are based on projections for individual tree species, or tree species groups. This feature can be used to disaggregate EFISCEN results by linking tree species in EFISCEN with spatially-explicit tree species maps. The approach has been developed and applied by Elbersen et al. (2012) and has been formalised in the EFISCEN disaggregation tool (Verkerk et al. 2016). The EFISCEN disaggregation tool was used to disaggregate the estimated biomass potentials to the 1km grid level using tree species distribution maps (Brus et al. 2011). The disaggregated woody biomass potentials were then multiplied with the respective constraint map. The resulting maps give the constrained potential at grid level. The rasters were then re-aggregated to NUTS 3 regions, as used in S2BIOM.

Methods to determine User defined potentials considering competing use

In order to consider the material use of wood as a constraint two constraint levels are defined:

Constraining the stemwood potential by the wood production for material use

The following FAO Production categories have been considered and totaled up per species group

- Sawlogs & Veneer Logs (C) + Pulpwood, Round & Split(C) + Other Industrial Roundwood (C)
- Sawlogs & Veneer Logs (NC) + Pulpwood, Round & Split(NC) + Other Industrial Roundwood (NC)

The total reduction was split into thinning and final harvests proportional to the supply potential of these two categories, this was applied separately for conifers and non-conifers. Bark was added to the FAOSTAT production data using the average volume ratio wood/ bark plus wood (UNECE FA0 2010).

Applying this reduction on the base potential resulted in UD5 (the data on primary forest residues remain unchanged).

Applying this reduction on the UD4 resulted in UD7 (the data on primary forest residues remain unchanged).

Constraining the stemwood potential by the wood production for material use except for pulp and paper and board industry

The same approach was used here, but merely Sawlogs & Veneer Logs & Other Industrial Roundwood where considered and totaled up for the reduction.

Applying this reduction on the base potential resulted in UD6 (the data on primary forest residues remain unchanged)..

Applying this reduction on the UD4 resulted in UD8 (the data on primary forest residues remain unchanged).

The underlying definitions of the FAOSTAT production data are presented below.

Sawlogs + Veneer Logs (C) Sawlogs + Veneer Logs (NC)	Roundwood that will be sawn (or chipped) lengthways for the manufacture of sawnwood or railway sleepers (ties) or used for the production of veneer (mainly by peeling or slicing). **It includes** roundwood (whether or not it is roughly squared) that will be used for these purposes; shingle bolts and stave bolts; match billets and other special types of roundwood (e.g. burls and roots, etc.) used for veneer production. **It is reported in** cubic metres solid volume underbark (i.e. excluding bark).
Pulpwood, Round & Split (C) Pulpwood Round & Split (NC)	Roundwood that will be used for the production of pulp, particleboard or fibreboard. **It includes:** roundwood (with or without bark) that will be used for these purposes in its round form or as splitwood or wood chips made directly (i.e. in the forest) from roundwood. **It is reported** in cubic metres solid volume underbark (i.e. excluding bark).
Other Industrial Roundwood (C) Other Industrial Roundwood (NC)	Industrial roundwood (wood in the rough) other than sawlogs, veneer logs and/or pulpwood. **It includes** roundwood that will be used for poles, piling, posts, fencing, pitprops, tanning, distillation and match blocks, etc. **It is reported in** cubic metres solid volume underbark (i.e. excluding bark).

Source: FAOSTAT forest product definitions (http://faostat.fao.org/Portals/_Faostat/documents/pdf/FAOSTAT-Forestry-def-e.pdf).

For the Western Balkans countries Montenegro, FYROM, Albania, Bosnia and Herzegovina, Serbia, Kosovo and Croatia–improved and slightly higher data on the round wood production have been used considering estimates provided by the ''The Sector Study on Biomass-based Heating in the Western Balkans'', World Bank, 2016, resulting in average increase for industrial roundwood vs the FAOSTAT production data by a factor of 1.25 and in case if fuelwood by a factor of 1.7.

For Germany the FAOSTAT data have been corrected considering a recent study from Jochem et al. (2015) that showed that part of the production data are on average not included in the amounts reported, namely 14% of the industrial round wood and 52% in case of fuelwood.

For other countries similar underreporting may apply as well, but no information was available.

2.5.3 Methods to estimate costs

2.5.3.1 Introduction

The estimation of harvesting and comminution costs is following the approach presented earlier by Ranta (2002, 2005), Ilavský et al. (2007), Anttila et al. (2011) and Laitila et al. (2015). In contrast to the cost estimates for energy crops, the production costs are not considered in the cost estimates.

The estimation of costs is described here for the following biomass categories:

1.1.1.1 Stemwood from final fellings originating from broadleaf trees

1.1.1.2 Stemwood from final fellings originating from conifer trees

1.1.1.3 Stemwood from thinnings originating from broadleaf trees

1.1.1.4 Stemwood from thinnings originating from conifer trees

1.2.1.1 Logging residues from final fellings originating from broadleaf trees

1.2.1.2 Logging residues from final fellings originating from conifer trees

1.2.2.1 Stumps from final fellings originating from broadleaf trees

1.2.2.2 Stumps from final fellings originating from conifer trees

The data are mostly determined by the S2Biom project. A survey of cost factors related to forest harvesting operations was carried out in cooperation with INFRES project (Dees et al. 2015).

The general work flow is illustrated in Figure 10. The methodology can be divided into two main components: 1) the estimation of hourly machine costs, and 2) the estimation of productivity. All the cost estimations pertain to current cost level (year 2012).

2.5.3.1 Machine costs

In order to enable better comparison of costs between regions, supply chains were standardised. The dominant supply chain for stemwood in Europe is the chain based on roadside chipping (Díaz-Yáñez et al. 2013, Junginger et al. 2005, Eriksson et al. 2013, Holzleitner et al. 2013, Rottensteiner et al. 2013, Routa et al. 2013, Wolfsmayr and Rauch 2014). In the chain felling and bunching are carried out by a harvester, off-road transport by a forwarder and chipping by a mobile chipper (Figure 11). For logging residues the chain is otherwise similar except for the missing felling phase. Instead, piling of logging residues by the harvester is considered to belong to logging residue supply chain. Stumps are extracted by an excavator, forwarded to roadside and crushed by a mobile grinder.

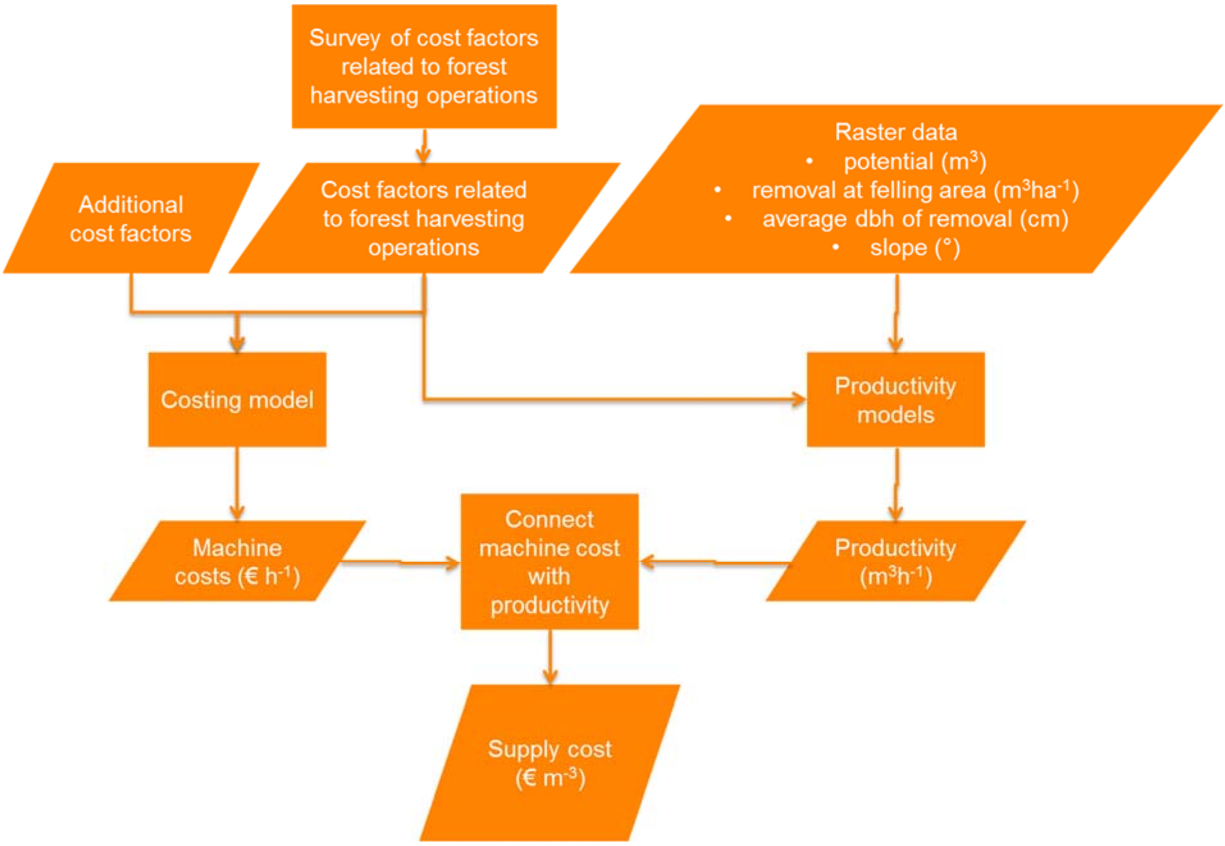


Figure 10. General work flow of the forest biomass cost calculations

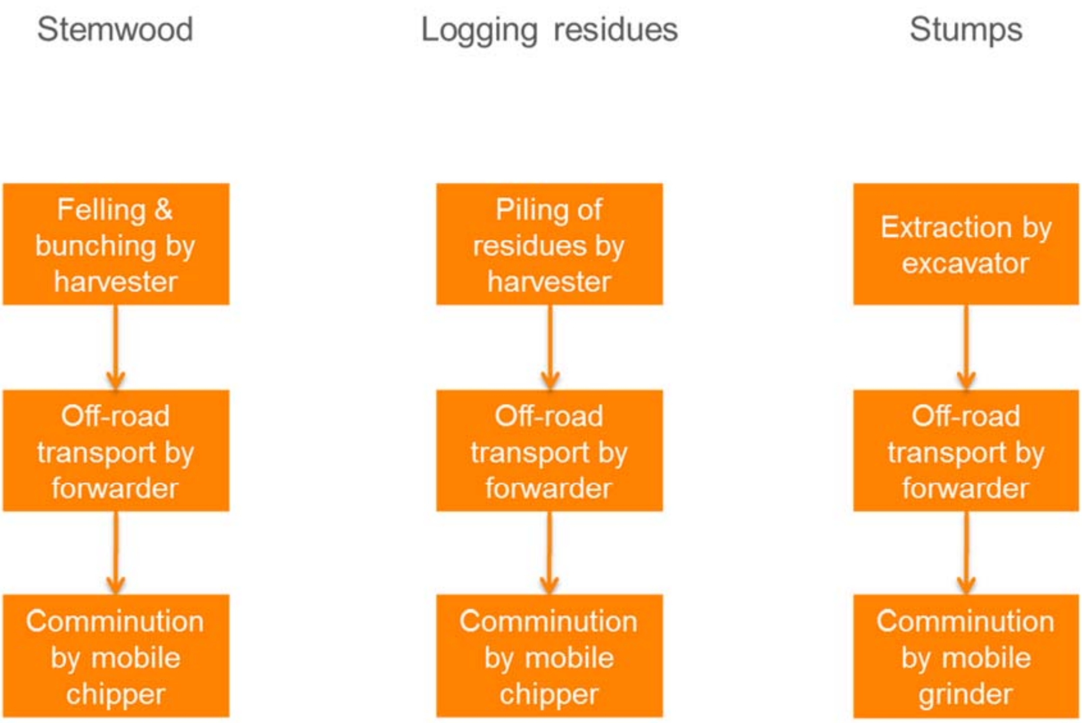


Figure 11 The supply chains selected in the study

A costing model developed for the Cost Action FP0902 ("Development and harmonization of new operational research and assessment procedures for sustainable forest biomass supply") was utilized in machine cost calculations (Ackerman et al. 2014). The Microsoft Excel –based tool provides an easy and harmonized way to compare the machine costs between the countries.

For this study, the input of the costing model consisted of both machine-level and country-level data. The machine-level data are described in Table 23. The degrees of machine utilization were based on the study by Laitila et al. (2010). Fuel consumption data has been collected by Laitila et al. (2012) except for the grinder, for which the consumption has been measured by Eliasson et al. (2012). Oil and lubricant costs as well as maintenance and repair costs have been assessed by Laitila and Väätäinen (2011) and Nurminen et al. (2009). For all the machines 1700 productive hours per annum and 12,000 in total (Laitila et al. 2010) were assumed. For the other input parameters the default values of the costing model were assumed.

Table 23 Machine-level input data

	Harvester	Excavator	Forwarder	Chipper	Grinder
Machine utilisation	80 %	88 %	85 %	65 %	65 %
Fuel consumption (lh^{-1})	11.0	18.0	9.5	45.0	68.6
Insurance (€)	3750	1800	2500	5400	7300
Oil and lubricant cost (% of fuel cost)	15 %	5 %	5 %	15 %	15 %
Maintenance and repair cost (% of fuel cost)	51 %	34 %	34 %	41 %	41 %

A total of six machine dealers were interviewed for purchase prices in Finland. The price of a single-grip harvester is the average of three and the price of a forwarder the average of four small-to-medium-sized machines. The excavator price includes a stump harvester. All the prices include equipment and exclude VAT. Subsequently, price level indices of 2012 were used to calculate machine prices for each country after the country-specific indices (EUROSTAT 2015a) based on the Finnish purchasing prices (Table 24). The price level indices for Ukraine and Moldova were assumed to be the same as in Romania, for Kosovo the Serbian values were assumed.

Table 24 Purchase prices of the machines

		Machine price after index (€)				
	Machine price level indices (2012)	Harvester	Excavator	Forwarder	Chipper	Grinder
Belgium	103	341210	163781	227473	491343	664223
Bulgaria	92.4	306095	146926	204064	440777	595866
Czech Republic	98.4	325972	156466	217314	469399	634558
Denmark	122.6	406140	194947	270760	584841	790618
Germany	97.7	323653	155353	215769	466060	630044

	Machine price level indices (2012)	Machine price after index (€)				
		Harvester	Excavator	Forwarder	Chipper	Grinder
Estonia	96.2	318684	152968	212456	458905	620371
Ireland	105	347836	166961	231890	500883	677120
Greece	112.1	371356	178251	247571	534753	722906
Spain	98.2	325309	156148	216873	468445	633269
France	98.9	327628	157261	218419	471784	637783
Italy	100	331272	159011	220848	477032	644876
Cyprus	105.3	348830	167438	232553	502314	679055
Latvia	99.8	330610	158693	220406	476078	643587
Lithuania	93.4	309408	148516	206272	445548	602314
Luxembourg	100.8	333922	160283	222615	480848	650035
Hungary	89.4	296157	142155	197438	426466	576519
Malta	110	364399	174912	242933	524735	709364
Netherlands	102.3	338891	162668	225928	488004	659708
Austria	102.4	339223	162827	226148	488481	660353
Poland	94.8	314046	150742	209364	452226	611343
Portugal	106.1	351480	168710	234320	506131	684214
Romania	96.5	319678	153445	213118	460336	622306
Slovenia	96.9	321003	154081	214002	462244	624885
Slovakia	105	347836	166961	231890	500883	677120
Finland	113.2	375000	180000	250000	540000	730000
Sweden	113	374337	179682	249558	539046	728710
United Kingdom	98.8	327297	157102	218198	471307	637138
Croatia	96.2	318684	152968	212456	458905	620371
Albania	95.7	317027	152173	211352	456519	617147
Bosnia and Herzegovina	100.1	331603	159170	221069	477509	645521
Macedonia	93.8	310733	149152	207155	447456	604894
Montenegro	97.6	323322	155194	215548	465583	629399
Serbia	90.3	299139	143587	199426	430760	582323
Kosovo	90.3	299139	143587	199426	430760	582323
Ukraine	96.5	319678	153445	213118	460336	622306
Turkey	98	324647	155830	216431	467491	631979
Moldova	96.5	319678	153445	213118	460336	622306

The rest of the country-level data consisted of fuel price, labour costs and interest rate (Table 25). The fuel costs were taken from Oil bulletin (DG Energy 2015), prices of automotive diesel in 2012 with taxes reduced by the VAT in 2012. The fuel costs for Albania, Bosnia and Herzegovina, Croatia, Macedonia, Montenegro, Serbia, Kosovo, Turkey, Ukraine and Moldova were calculated by multiplying the pump fuel price available for all countries (obtained October 30th 2015 from: http://www.fuel-prices-europe.info/) with the ratio between the average fuel price of available countries without VAT and the pump fuel price on October 30th 2015. Fuel cost data was also collected in a separate survey (Dees et al. 2015), but due to poor coverage the data will be used in the validation of the final result only.

Table 25 Country-level input data

		Labour cost (€h^{-1})					
	Fuel cost (€l^{-1})	Felling	Stump lifting	Forwarding	Chipping	Grinding	Interest rate
Belgium	1.16	42.92	42.92	35.75	42.92	42.92	3.03 %
Bulgaria	1.02	3.29	3.29	3.54	3.29	3.29	3.03 %
Czech Republic	1.16	9.95	9.95	9.38	9.95	9.95	3.03 %
Denmark	1.12	40.71	40.71	37.71	40.71	40.71	3.03 %
Germany	1.21	35.22	35.22	25.49	35.22	35.22	3.03 %
Estonia	1.10	8.55	8.55	8.75	8.55	8.55	3.03 %
Ireland	1.19	31.75	31.75	28.92	31.75	31.75	3.03 %
Greece	1.18	16.31	16.31	19.12	16.31	16.31	3.03 %
Spain	1.11	23.03	23.03	21.45	23.03	23.03	3.03 %
France	1.12	36.38	36.38	32.18	36.38	36.38	3.03 %
Italy	1.35	27.20	27.20	24.73	27.20	27.20	3.03 %
Cyprus	1.13	15.32	15.32	19.08	15.32	15.32	3.03 %
Latvia	1.08	5.88	5.88	6.90	5.88	5.88	3.03 %
Lithuania	1.05	5.72	5.72	6.64	5.72	5.72	3.03 %
Luxembourg	1.07	30.73	30.73	30.76	30.73	30.73	3.03 %
Hungary	1.10	7.81	7.81	7.48	7.81	7.81	3.03 %
Malta	1.13	11.57	11.57	10.65	11.57	11.57	3.03 %
Netherlands	1.16	33.90	33.90	28.54	33.90	33.90	3.03 %
Austria	1.13	33.01	33.01	27.89	33.01	33.01	3.03 %
Poland	1.04	7.74	7.74	7.01	7.74	7.74	3.03 %
Portugal	1.12	10.99	10.99	15.02	10.99	10.99	3.03 %
Romania	1.00	4.17	4.17	4.53	4.17	4.17	3.03 %
Slovenia	1.09	15.13	15.13	15.12	15.13	15.13	3.03 %
Slovakia	1.15	9.18	9.18	7.94	9.18	9.18	3.03 %
Finland	1.20	35.03	35.03	29.69	35.03	35.03	3.03 %
Sweden	1.25	41.70	41.70	33.82	41.70	41.70	3.03 %
United Kingdom	1.45	21.73	21.73	21.22	21.73	21.73	3.03 %
Croatia	1.12	8.48	8.48	9.63	8.48	8.48	3.03 %
Albania	1.29	4.96	4.96	4.83	4.96	4.96	3.03 %
Bosnia and Herzegovina	1.09	4.96	4.96	4.83	4.96	4.96	3.03 %
Macedonia	0.83	4.96	4.96	4.83	4.96	4.96	3.03 %
Montenegro	1.07	7.31	7.31	5.68	7.31	7.31	3.03 %
Serbia	1.15	4.96	4.96	4.83	4.96	4.96	3.03 %
Kosovo	1.00	4.96	4.96	4.83	4.96	4.96	3.03 %
Ukraine	0.67	2.30	2.30	2.30	2.30	2.30	3.03 %
Turkey	1.19	5.68	5.68	5.91	5.68	5.68	3.03 %
Moldova	0.72	2.30	2.30	2.30	2.30	2.30	3.03 %

The data source for the labour costs was EUROSTAT (EUROSTAT 2015b). The definition of labour costs is as follows: "Labour Costs refer to the total expenditure borne by employers for the purpose of employing staff. They include employee compensation, which is mainly comprised of gross wages and salaries in cash and in kind and employers' social security contributions, vocational training costs, other expenditure, such as recruitment costs and spending on working clothes, and employment taxes regarded as labour costs minus subsidies received." (EUROSTAT 2015).

As no data for the exact work categories of this study were available, labour costs of class "Industry – except construction" were used for felling, stump extraction, chipping and grinding and costs of class "Transportation and storage" for forwarding. For Malta the missing transportation value was calculated by multiplying the industry value by the average ratio of costs for "Transportation and storage" and the costs "Industry – except construction". For countries where the data were missing, the numbers of neighbouring countries were used: for Albania, Bosnia and Herzegovina, Macedonia and Kosovo the numbers of Serbia. Like with fuel costs the survey data (Dees et al. 2015) will only be used for validation except for Ukraine for which the survey data was used in calculation. For Moldova the numbers of Ukraine were used.

As a reference interest rate for forest machine investments MFI-indicators have been used (European Central Bank 2013). The values to loan size "Over an amount of EUR 250,000 and up to EUR 1 million" in Table 26 and the category "Floating rate and up to three months initial rate fixation" with the average of all the months in 2012 have been used. For all countries the Euro zone values were applied.

The resulting country-level costs of the machines are listed in Table 26.

Table 26 The country-level machine costs (€h^{-1})

	Harvester	Excavator	Forwarder	Chipper	Grinder
Belgium	113	90	80	189	243
Bulgaria	58	40	38	115	163
Czech Republic	70	51	48	136	189
Denmark	118	90	87	195	251
Germany	102	81	67	177	231
Estonia	67	48	46	129	180
Ireland	101	78	73	175	230
Greece	84	61	63	155	211
Spain	86	65	62	153	204
France	103	81	75	175	227
Italy	95	75	68	173	231
Cyprus	79	58	61	146	200
Latvia	65	45	45	126	177
Lithuania	62	44	42	121	170
Luxembourg	96	74	73	165	216
Hungary	63	46	43	124	174

Malta	77	55	52	143	197
Netherlands	102	79	72	175	229
Austria	100	78	70	172	225
Poland	65	46	43	125	173
Portugal	74	53	56	140	193
Romania	60	42	40	118	166
Slovenia	75	56	54	139	190
Slovakia	72	52	48	138	192
Finland	108	83	76	185	242
Sweden	117	92	81	198	256
United Kingdom	89	70	65	169	230
Croatia	67	49	47	130	182
Albania	65	48	43	133	189
Bosnia and Herzegovina	64	45	42	125	177
Macedonia	58	39	38	109	152
Montenegro	65	47	43	127	177
Serbia	61	44	41	123	174
Kosovo	59	41	39	115	162
Ukraine	54	33	34	98	137
Turkey	65	47	44	131	184
Moldova	54	34	35	100	141

2.5.3.2 Productivity

Productivities of machines and the dependences of the productivities on the operating environment have been formulated in productivity models based on field measurements. In order to enable the comparability between countries only one model was selected for each biomass category and machine (Table 27). The productivities (m^3h^{-1}) and further unit costs (€m^{-3}) were estimated at NUTS3 (or corresponding regions defined in the project) level.

Table 27 The applied productivity models by biomass categories. The same models were applied for both broadleaf and conifer trees

Biomass category	Mechanized felling & bunching	Integrated bunching while felling with a harvester	Forwarding	Chipping	Stump lifting	Crushing
Stemwood from final fellings	Kuitto et al. (1994)	N/A	Kuitto et al. (1994)	Laitila (2006)	N/A	N/A
Stemwood from thinnings	Kuitto et al. (1994)	N/A	Kuitto et al. (1994)	Laitila (2006)	N/A	N/A
Logging residues from final fellings	N/A	Laitila (2006)	Ranta (2002)	Laitila (2006)	N/A	N/A

Stumps from final fellings	N/A	N/A	Laitila (2010)	N/A	Laitila et al. (2008)	Nuutinen et al. (2014)

2.5.3.3 Operating environment

In addition to the properties of forest machines a large part of their productivity can be explained by the properties of the operating environment. In order to take the properties of forest stands to be harvested into account raster data was delivered by the European Forest Institute. The data included the intensity of harvesting (m^3ha^{-1}) for final fellings and thinnings separately for broadleafs and conifers as well as the average diameter (cm) of removed trees for the same classes in a 1 km x 1 km grid. The grid data were aggregated to NUTS3 level to be used as input parameters for productivity models.

In case harvesting intensity or diameter data were missing, a calculation using average values of near-neighbour countries or regions was performed. In the case of Bosnia and Herzegovina, Kosovo, Montenegro and Serbia the average over country averages using data from Albania, Bulgaria, Croatia, Romania were calculated. Missing values for Cyprus were substituted with conifer country average values from Turkey. Missing broadleaved harvesting intensity and diameter data from Croatia were substituted with country averages from Hungary, Slovenian data with Austrian values respectively. Albanian average values were used for missing values in Greece. Missing conifer data on diameters in Luxembourg were replaced with average from the neighbouring regions BE342, DEB23, FR413, the Ukrainian region UA11I was calculated from the average of the neighbouring regions UA117, UA11D, UA119, UA11J. Macedonian missing data were substituted with the average of the Albanian and Bulgarian country averages.

In some rare cases the estimated values for harvesting intensity or diameter were outside the range of data values used in modeling productivity resulting unrealistic cost estimates. In these cases costs could not be estimates.

The effect of slope was considered by multiplying the time consumption of forwarding by a driving speed factor determined by the steepness of slope (Table 28). The slope values were calculated by using the Digital Elevation Model over Europe from the GMES RDA project iin a spatial resolution of 25 m that was derived from the original posting of 1 arc sec (~30m) with an overall vertical accuracy of 2.9 meters RMSE [root mean square error] (DHI GRAS 2014). Other factors describing the operating environment were acquired from the survey or literature.

Table 28 Driving speed factors for forwarding (Ilavský et al. 2007)

Slope category	0 – 10 %	10 – 20 %	20 – 30 %	30 – 40 %	40 – 50 %
Driving speed factor	1.00	1.11	1.35	1.79	2.78

2.5.3.4 Biomass models

The intensity of harvesting or average diameter may not be directly usable as explanatory variables of productivity model. In order to estimate such variables, the countries were divided into four groups (based on the categorization done in INFRES project, extended by additional countries within S2Biom):

- NEU: Northern Europe
- CEU: Central Europe
- EEU: Eastern Europe
- SEU: Southern Europe

Representative species were defined for each country group: One species for broadleaves, one for conifers (except for Southern Europe where two different Pinus spp. were used due to the limited availability of biomass models (Table 29)).

Table 29 The grouping of the countries and the selected species

Group	Country	Broadleaved	Conifers
CEU	Austria	Fagus spp.	Picea abies
CEU	Belgium	Fagus spp.	Picea abies
CEU	Germany	Fagus spp.	Picea abies
CEU	Denmark	Fagus spp.	Picea abies
CEU	France	Fagus spp.	Picea abies
CEU	Luxembourg	Fagus spp.	Picea abies
CEU	Netherlands	Fagus spp.	Picea abies
EEU	Czech Republic	Fagus spp.	Picea abies
EEU	Croatia	Fagus spp.	Picea abies
EEU	Hungary	Fagus spp.	Picea abies
EEU	Moldova	Fagus spp.	Picea abies
EEU	Poland	Fagus spp.	Picea abies
EEU	Romania	Fagus spp.	Picea abies
EEU	Slovenia	Fagus spp.	Picea abies
EEU	Slovakia	Fagus spp.	Picea abies
EEU	Ukraine	Fagus spp.	Picea abies
NEU	Estonia	Betula spp.	Picea abies
NEU	Finland	Betula spp.	Picea abies
NEU	Ireland	Betula spp.	Picea abies
NEU	Lithuania	Betula spp.	Picea abies
NEU	Latvia	Betula spp.	Picea abies
NEU	Sweden	Betula spp.	Picea abies
NEU	United Kingdom	Betula spp.	Picea abies
SEU	Albania	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Bosnia and Herzegovina	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Bulgaria	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Cyprus	Quercus ilex	Pinus sylvestris/ Pinus radiata

Group	Country	Broadleaved	Conifers
SEU	Greece	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Spain	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Italy	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Montenegro	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Macedonia	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Malta	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Portugal	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Serbia	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Turkey	Quercus ilex	Pinus sylvestris/ Pinus radiata
SEU	Kosovo	Quercus ilex	Pinus sylvestris/ Pinus radiata

The biomass and stem volume functions applied for the four country categories are given in Table 30.

Table 30 The biomass and volume functions applied in the study.

Biomass category	NEU	CEU	EEU	SEU
1.1.1.1 Stemwood from final fellings originating from broadleaf trees	Repola (2008)	Pellinen (1986)	Pellinen (1986)	Brandini & Tabacchi (1996)
1.1.1.2 Stemwood from final fellings originating from conifer trees	Repola (2009)	Černý (1990)	Černý (1990)	Corona & Ferrara (1987)
1.1.1.3 Stemwood from thinnings originating from broadleaf trees	Repola (2008)	Pellinen (1986)	Pellinen (1986)	Brandini & Tabacchi (1996)
1.1.1.4 Stemwood from thinnings originating from conifer trees	Repola (2009)	Černý (1990)	Černý (1990)	Corona & Ferrara (1987)
1.2.1.1 Logging residues from final fellings originating from broadleaf trees	Repola (2008)	Pretzsch (2000)	Pretzsch (2000)	Brandini & Tabacchi (1996)
1.2.1.2 Logging residues from final fellings originating from conifer trees	Repola (2009)	Fiedler (1986)	Černý (1990)	Menguzzato & Tabacchi (1988)
1.2.2.1 Stumps from final fellings originating from broadleaf trees	Repola (2008)	N/A	N/A	N/A
1.2.2.2 Stumps from final fellings originating from conifer trees	Repola (2009)	N/A	N/A	N/A

2.5.3.5 Stemwood from final fellings and thinnings

The process of felling and bunching comprises of moving in the felling area and processing the trees (Kuitto et al. 1994). The time consumption of moving depends on the number of removed trees per hectare. This was estimated based on the harvesting intensity and average stem volume. The average stem volume also explains tree processing time. Finally, the productivity of felling and bunching was calculated as a function of the two above-mentioned and corrected by factor of 1.3, which was assumed to be the ratio between gross effective and effective time (Laitila et al. 2010).

The process of forwarding consists of loading the forwarder, driving during loading, driving when empty, driving when loaded and unloading the forwarder (Kuitto et al.

1994). Time consumption of loading and driving during loading depend on harvesting intensity and the load size of the forwarder (Table 31), the one of driving on forwarding distance (Dees et al. 2015) and the one of unloading on the load size. The gross effective / effective time ratio was set at 1.2 (Laitila et al. 2010).

Table 31 Forwarder load capacity in solid cubic metres for the different biomass categories

	m^3	Source
Stemwood from final fellings originating from broadleaf trees	10.24	Kuitto et al. (1994)
Stemwood from final fellings originating from conifer trees	12.8	Kuitto et al. (1994)
Stemwood from thinnings originating from broadleaf trees	8	Kuitto et al. (1994)
Stemwood from thinnings originating from conifer trees	10	Kuitto et al. (1994)
Logging residues from final fellings originating from broadleaf trees	7.8	Laitila et al. (2010)
Logging residues from final fellings originating from conifer trees	7.8	Laitila et al. (2010)
Stumps from final fellings originating from broadleaf trees	8.6	Laitila et al. (2010)
Stumps from final fellings originating from conifer trees	8.6	Laitila et al. (2010)

The productivity of chipping per effective machine hour was assumed to be 85 loose cubic metres (Laitila 2006). The degree of machine utilization was set at 65% (Laitila et al. 2010).

The costs of wood production were not considered in this study.

2.5.3.6 Logging residues from final fellings

With logging residues from final fellings no direct cost is incurred for felling. However, for logging residues to be forwarded efficiently, they have to be bunched by the harvester during felling. The contractor may be paid a small compensation for bunching. Here, a value of 0.3 €m^{-3} was used (Laitila 2006). The models of Ranta (2002) were used for time consumption for forwarding. Chipping productivity was set at 70 loose cubic metres (Laitila 2006).

2.5.3.7 Stumps from final fellings

Stump extraction time was divided to excavator moving time and processing time (Laitila et al. 2008). The moving time was determined by the intensity of harvesting, i.e. the number of stumps to be extracted. The processing time is explained by stump diameter. The gross effective / effective time ratio for an excavator was set at 1.1 (Laitila et al. 2010). The time consumption of forwarding was estimated with the models by Laitila et al. (2008). Grinding productivity was set at the level of 36 m^3h^{-1} observed by Nuutinen et al. (2014).

2.5.3.8 Uncertainties

Without quantifying their magnitude at least the following uncertainties of the estimation procedure can be identified. In addition, for each of the problems potential measures to alleviate it are given.

- Only one supply chain per biomass category was determined. Although the dominating chains in Europe were chosen their feasibility varies from country to another. However, choosing different chains for the countries would impair the comparability of the costs between the countries. → Add more supply chains.
- Part of the machine-level input data were assumed constant among the countries. In reality there are differences between countries in, e.g., utilization rate. → Machine data could be made country specific, if country-level data exist.
- Labour costs are based on Eurostat data where the work categories are rather broad. E.g. the real labour cost of a harvester operator may differ from labour costs of class “Industry – except construction”. → Check the Eurostat data against country-level survey data.
- Only one productivity model per biomass category and work phase was applied. The reason for this was, again, the attempt keep the costs comparable between the countries. → Compare the results with additional models. In the comparison it should be noted that often the models are based on a very limited number of operators. It is however well known, that the effect of an operator on productivity is large (e.g. Purfürst & Erler 2011). Therefore studies with extensive data should be preferred.
- The accuracy of the intensity and average diameter data is unknown. → Validate the estimations with measured data.
- Estimation of stem, crown and stump volumes was simplified so that only one species for each of the four country categories was selected. The grouping of the countries was more or less arbitrary and the selection of species depended on the availability of volume and biomass functions. → Add models for the countries and species where available.
- Generally much of the input data is difficult to obtain at regional or even country level. E.g. in most of the countries there exist no statistics on forwarding distances, but the answers given in the survey were mostly educated guesses. → Collect relevant data at country level.

2.6 Other land use

2.6.1 Potential categories and potential types

There are many biomass sources that can be assessed from the other land uses category such as grassland cuttings from nature protection areas, recreational areas, dykes and from road side verges. The woody biomass potentials can also come from road side verges and from landscape maintenance. Properly assessing their quantities requires a lot of high resolution data not only on the land use and land cover classes, but also on the type of vegetation present to make a proper estimate of the amount of biomass produced and the cutting and wider management requirements and practices and management and ownership structure.

Table 32 Subcategories of "Other Landuse"

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
312	Biomass from road side verges	3121	Grassy biomass from road side verges

Because of the lack of high resolution data, particularly in relation management practices and vegetation types/species distribution and limited time to invest in collection of data the focus in S2BIOM was only on the road side verge grassland potential. A distinction in assessment was not made between the technical and base potential as in both the maximum amount of removable biomass is assumed.

2.6.2 Methods to estimate the supply potential

The assessment of potential biomass from road side verges builds on the assessments already done as part of the Biomass Futures (Elbersen, et al.,2012) and Biomass Policies (Elbersen et al., 2015) projects and the results of this assessment were further refined and extrapolated to 2012, 2020 and 2030 in S2BIOM.

For the assessment the road side verge grass potential an EU-wide road network map (ESRI roads (Europe Roads represents the roads (European Highway System, national, and secondary roads) and de roads network database, Eurostat 2010) was used as a basis. It was combined with a more precise road network map for The Netherlands (TOP10, Kadaster) because the European-wide data sources only contain the main roads, the more detailed information from The Netherlands could be used and extrapolated European wide using road density relations between the 3 data sources to the EU-wide data layer. A 10 meter boundary was assumed along both sides of the road and along the total road length in every region for which an average grassland potential was calculated. The average road verge size estimation was made based on an analysis of aerial photographs (AEROGRID) and Google Maps.

For the estimation of the grassland yield we build on Smit et al. (2008) who estimated average grassland productivity factors for different types of grassland per environmental zone in Europe. The type of grassland used in this map was assumed to be the most extensive grassland type assuming no fertilisation and poor soils. The environmental zonation ensures that grassland productivity is directly linked to climatic factors such as rainfall, evapotranspiration and length of growing season.

For future assessments it is assumed that the road network and thus the road side verge grass potential will increase according to GDP growth. As growth in the GDP will be reflected in extra investments for increasing the road network in a country. The road side verge grass yield levels were kept constant in time.

2.6.3 Methods to estimate costs

The cost for the type 'road side verge grass' falling in this other land use category has been assessed using the same ABC model as applied for agricultural biomass (see Sections 2.3.2 and 2.4.2). The cost allocated consist of:

1) Mowing
2) Racking which is needed to dry the cuttings before baling
3) Baling
4) Collection and loading at the road side

Although the cost for mowing is part of normal road side management we still allocate these cost to the cuttings because we expect higher mowing frequency if cuttings have a use. Collection and loading at the road side can be a time consuming activity because it needs to be done along a road, where traffic can be busy and space to work limited.

One can argue whether cost for traffic management and road blocking need to be incorporated. In this calculation we have not done it.

2.7 Secondary residues from wood industry

2.7.1 Potential categories and potential types

Secondary forest residues (SFR) comprise residues from saw mills, other wood processing industry residues and residues from pulp and paper industry (see Table 33).

Table 33 Subcategories of second level category 41 “Secondary residues from wood industries”

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
411	Saw mill residues	4111	Sawdust from sawmills from conifers
		4112	Sawdust from sawmills from nonconifers
		4113	Sawmill residues: excluding sawdust, conifers
		4114	Sawmill residues: excluding sawdust, nonconifers
412	Other wood processing industry residues	4121	Residues from industries producing semi -finished wood based panels
		4122	Residues from further wood processing
413	Secondary residues from pulp and paper industry	4131	Bark residues from pulp and paper industry
		4132	Black liquor

<u>Technical potential & Base potential</u>

For SFR no constraints are considered in the technical and base potential.

Table 34 Constraints applied for secondary forest residues, technical potential and base potential

Potential type	Area / Source	Yield, Growth	Technical & environmental constraints	Consideration of competing use
Technical potential = Base potential	The amount of SFR is determined on the basis of the current and assumed future industry production in the wood industry per spatial unit (national level to NUTS3 level)	Not applicable	None.	None

<u>User defined potentials</u>

User defined option 1 considers the residues from the entire wood industry sectors production.

To avoid double accounting inside the secondary forest residues domain in user defined potential 1 residues from saw mill industry that are utilised by other wood industry sectors are not regarded a potential since they are used for product generation designated for material use.

This potential is determined to allow the determination of the potential of SFR for the utilisation for

- Energy
- New biobased materials production

User defined option 1 can be used in combination with the potential from forestry where the production of assortments for material are used as a constraint (UD5, UD7) in order to assess the potential from both forestry & SFR for the above mentioned purposes.

User defined option 2 considers merely the residues from the wood industry sectors sawmills industry and veneer and plywood.

This potential is determined to allow the determination of the potential of SFR for the utilisation for

- Energy
- New biobased materials production
- Pulp production
- Board production.

User defined option 2 can be used in combination with the potential from forestry where merely the production of assortments for sawmill, veneer and plywood industry is considered a constraint (UD6, UD8) in order to assess the potential from both forestry & SFR for the above mentioned purposes. Details per subcategory are shown in Table 35.

Table 35 Constraints considering competing use applied for secondary forest residues, user defined potentials

Option	Scope	Constraints per category	
User defined potential 1 (U1)	Considering residues from all wood industry sectors	Saw mill residues	Reduced by the amount of residues that are utilised by the pulp and board production
		Residues from industries producing semi -finished wood based panels	None
		Residues from further wood processing	None
		Secondary residues from pulp and paper industry	None
User defined potential 2 (U2)	Considering residues from saw mills, plywood & veneer industry only	Saw mill residues	No reduction
		Residues from industries producing semi -finished wood based panels	Set to zero, except for residues from veneer & plywood
		Residues from further wood processing	Set to zero
		Secondary residues from pulp and paper industry	Set to zero

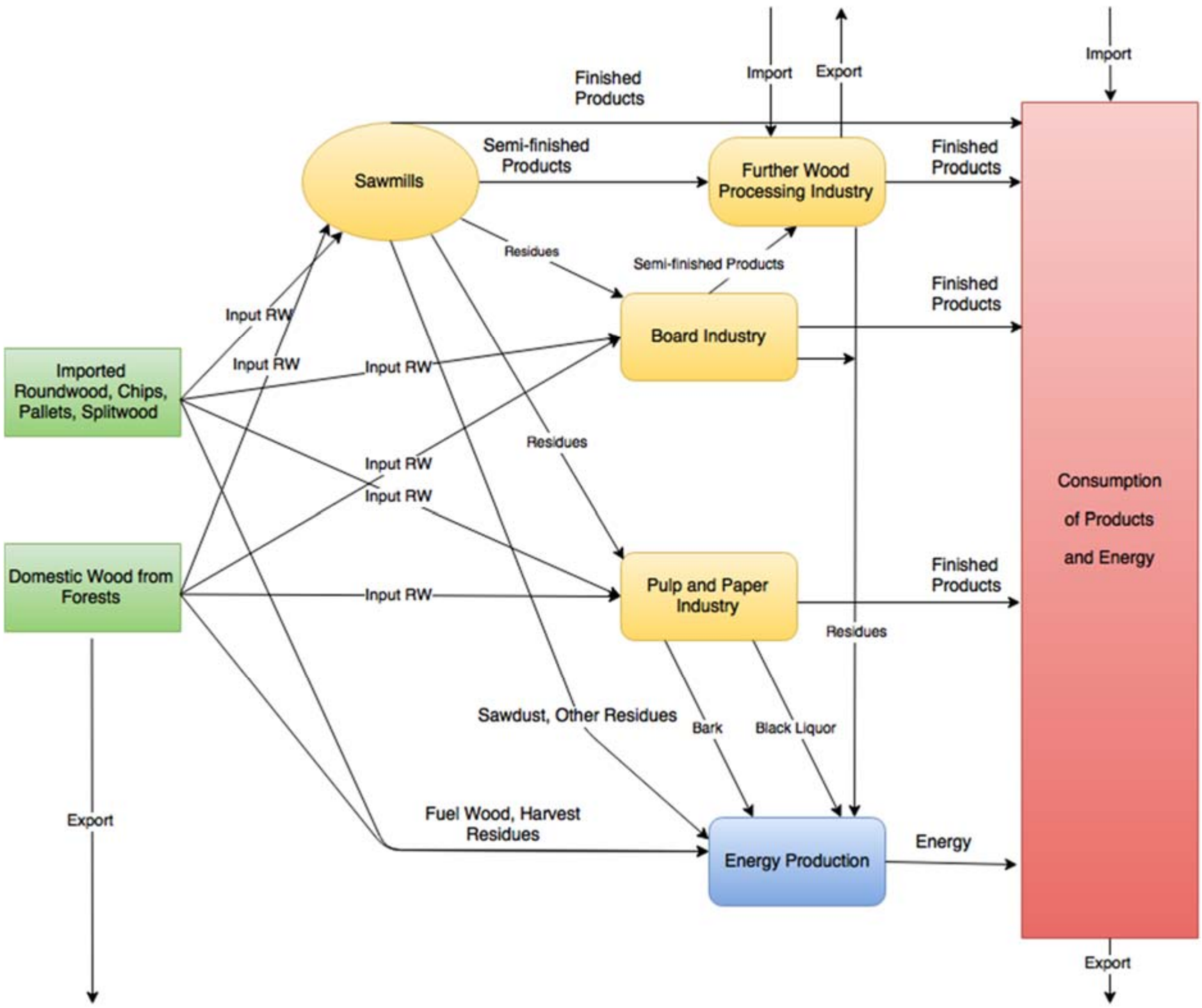


Figure 12 Material flow in the forest sector

The material flow of wood that is sketched in Figure 12. Summing up base potentials from forestry and SFR would result in double accounting, since the wood used by wood industry that's production results in secondary forest residues would be counted twice. Merely the import export balance effects can still not fully be addressed using the corresponding user defined potentials from forestry and SFR when totals are determined using the user defined potentials as described above.

SFR-potentials are determined first in volume units and then converted in weight units utilising the conversion factors documented in Table 36.

Table 36 Conversion factors and approach used to determine the supply potentials in volume and weight units for secondary forest residues

Final level subcategories		Kilogram dry matter of lignocellulose biomass per m3 volume unit	Moisture content assumed under this conversion	Source/ Comment
ID	Name	In: m Out: kg dm	In % of dry matter.	
4111	Sawdust from sawmills from conifers	442.1	16.9	Determine using data on round wood and sawn wood provided by UNECE /FAO (2010). Referring to the wood volume and moisture based of the wood product.

4112	Sawdust from sawmills from nonconifers	571.9	18.9	Determine using data on round wood and sawn wood provided by UNECE /FAO (2010). Referring to the wood volume and moisture based of the wood product.
4113	Sawmill residues: excluding sawdust, conifers	442.1	16.9	Determine using data on round wood and sawn wood provided by UNECE /FAO (2010). Referring to the wood volume and moisture based of the wood product.
4114	Sawmill residues: excluding sawdust, nonconifers	571.9	18.9	Determine using data on round wood and sawn wood provided by UNECE /FAO (2010). Referring to the wood volume and moisture based of the wood product.
4121	Residues from industries producing semi - finished wood based panels	448	52.3% (calculation based on round wood input units)	UNECE /FAO (2010) Value for round wood pulp, fuel wood logs c/nc Referring to the wood volume and moisture based of the Round wood product.
4122	Residues from further wood processing	509 (average)	Different by wood product ranging from 6 % to 18.9 %	Estimates in the data base are determined per sector and then summed up The conversion factors are based on own calculations considering the wood product properties and product share per sector utilising data from Germany in Mantau & Bilitevski (2010) and wood and wood product properties from UNECE /FAO (2010). The conversion factor used per sector is given below: Constr. 477.4 Furniture 574.2 Packaging 465.4 Other 520.9
4131	Bark residues from pulp and paper industry	373	52.3% (calculation based on round wood input units)	UNECE /FAO (2010) Value for bark
4132	Black liquor	448	52.3% (calculation based on round wood input units)	UNECE /FAO (2010); Value for round wood pulp, fuel wood logs c/nc

All potential levels are provided for 2012, 2020 and 2030.

2.7.2 Methods to estimate the supply potential

2.7.2.1 Introduction

The amount of secondary forest residues is directly related to the wood industry production. Based on statistical data from activity accounting efforts or on methods to estimate the production quantities or the round wood consumption (input per sector) the amounts of residues per wood industry sector are determined.

The methods are presented by industry sector:

- Resides from the saw mill industry divided in
    - Saw dust from conifer trees
    - Saw dust from non-conifer trees
    - Other residues from conifer trees

    - Other residues from non-conifer trees

- Residues from industry producing semi-finished wood based panels, including veneer sheets, plywood, particle board, OSB, MDF, hardboard and insulating board

- Residues from further processing, including construction, packaging, furniture and other types of further processing

- Residues from pulp and paper industry divided in

    - Bark

    - Black liquor

2.7.2.2 Saw mill residues

Saw mill residues are determined separately for conifers and non-conifers and for saw dust and other residues, comprising chips, slabs and shavings. To determine the **technical and base potential** of SFR the statistics on production volumes provided by FAOSTAT per country are used in combination with product recovery rates and the quantitative relation of residues to products.

For the current potential "2012" the FAOSTAT production data from 2010 to 2014 have been used to determine an average value in order to reduce the influence of annual market fluctuations.

The amounts of saw dust and other residues from sawmills are estimated using

SD-Q = P-Q * SD-P-Ratio

OR-Q = P-Q * OR-P-Ratio

Where SD-Q is standing for the saw dust quantity, P-Q for the product quantity, SD-P-Ratio for the sawdust to product ratio and where OR-Q is standing for the non-saw dust residues quantity and OR-P-Ratio for the other residues to product ratio.

These ratios can be determined using the recovery rate of the product and the share of saw dust and other residues that are provided by UNCECE/FAO (2010) and by Saal (2010a) using

SD-P-Ratio = SD% / RR%

OR-P-Ratio =OR%/ RR%

where RR% is standing product recovery rate, SD% for the share of saw dust and OR% for the share of other residues.

The ratios used for EU 27 countries are based on Saal (2010a). The ratios Turkey, Ukraine and Moldavia are based on an average of these values for the eastern and south-eastern EU countries Poland, Slovenia, Slovakia, Romania, Bulgaria, Czech Rep, and Hungary (see Table 37 and Table 38).

Table 37 Sawmill residue to product ratios per country, Conifers

Country	Country code	RR%	SD%	OR%	SD-P-Ratio	OR-P-Ratio
Austria	AT	61	13	26	0.213	0.426
Belgium	BE	60	14	26	0.233	0.433
Bulgaria	BG	55	16	29	0.291	0.527
Cyprus	CY	54	16	30	0.296	0.556
Czech Republic	CZ	60	14	26	0.233	0.433
Denmark	DK	59	15	26	0.254	0.441
Estonia	EE	53	16	31	0.302	0.585
Finland	FI	50	17	33	0.340	0.660
France	FR	62	13	25	0.210	0.403
Germany	DE	61	14	25	0.230	0.410
Greece	EL	58	15	27	0.259	0.466
Hungary	HU	55	16	29	0.291	0.527
Ireland	IE	53	17	30	0.321	0.566
Italy	IT	59	15	26	0.254	0.441
Latvia	LV	54	16	30	0.296	0.556
Lithuania	LT	50	17	33	0.340	0.660
Luxembourg	LU	59	13	28	0.220	0.475
Malta	MT	No data available; no data necessary since no data available from FAOSTAT.				
Netherlands	NL	60	14	26	0.233	0.433
Poland	PL	58	15	27	0.259	0.466
Portugal	PT	59	14	27	0.237	0.458
Romania	RO	58	15	27	0.259	0.466
Slovakia	SK	58	14	28	0.241	0.483
Slovenia	SI	58	15	27	0.259	0.466
Spain	ES	59	14	27	0.237	0.458
Sweden	SE	49	18	33	0.367	0.673
United Kingdom	UK	50	17	33	0.340	0.660
Turkey	TR	57.4	15	27,6	0.262	0.481
Ukraine	UA	57.4	15	27,6	0.262	0.481
Moldova	MD	57.4	15	27,6	0.262	0.481

Table 38 Sawmill residue to product ratios per country, Nonconifers

Country	Country code	RR%	SD%	OR%	SD-P-Ratio	OR-P-Ratio
Austria	AT	65	12	23	0.185	0.354
Belgium	BE	60	13	27	0.217	0.450
Bulgaria	BG	58	14	28	0.241	0.483
Cyprus	CY	47	18	35	0.383	0.745
Czech Republic	CZ	64	12	24	0.188	0.375
Denmark	DK	62	12	26	0.194	0.419
Estonia	EE	54	14	32	0.259	0.593
Finland	FI	54	15	31	0.278	0.574
France	FR	47	16	37	0.340	0.787
Germany	DE	65	12	23	0.185	0.354
Greece	EL	47	17	36	0.362	0.766
Hungary	HU	50	16	34	0.320	0.680
Ireland	IE	53	15	32	0.283	0.604
Italy	IT	60	13	27	0.217	0.450
Latvia	LV	50	16	34	0.320	0.680
Lithuania	LT	48	17	35	0.354	0.729
Luxembourg	LU	60	14	26	0.233	0.433
Malta	MT	No data available; no data necessary since no data available from FAOSTAT.				
Netherlands	NL	60	13	27	0.217	0.450
Poland	PL	55	15	30	0.273	0.545
Portugal	PT	47	17	36	0.362	0.766
Romania	RO	60	13	27	0.217	0.450

Slovakia	SK	66	10	24	0.152	0.364
Slovenia	SI	60	13	27	0.217	0.450
Spain	ES	53	15	32	0.283	0.604
Sweden	SE	53	15	32	0.283	0.604
United Kingdom	UK	40	20	40	0.500	1.000
Turkey	TR	59	13.3	27.7	0.229	0.478
Ukraine	UA	59	13.3	27.7	0.229	0.478
Moldova	MD	59	13.3	27.7	0.229	0.478

For the Western Balkans countries Montenegro, FYROM, Albania, Bosnia and Herzegovina, Serbia, Kosovo and Croatia a different approach was applied. Due to a lack of reliable data on production and consumption of sawnwood it is necessary to use the following formulae for calculation of P-Q (product quantity) using national level data sources:

P-Q= AC – I + E

AC Apparent consumption
I Import
E Export

The total production and consumption of wood residues will be recalculate through usage of conversion factors of final products into equivalent round wood m³ as described above using the ratios presented in Table 39.

Table 39 Sawmill residue to product ratios per Western Balkans countries,

Type	RR%	SD%	OR%	SD-P-Ratio	OR-P-Ratio
Conifers	59	15,0	26	0.254	0.441
Non-conifers, Croatia	57	17	26	0.298	0.456
Non-conifers, Other	55	17	28	0.309	0.509

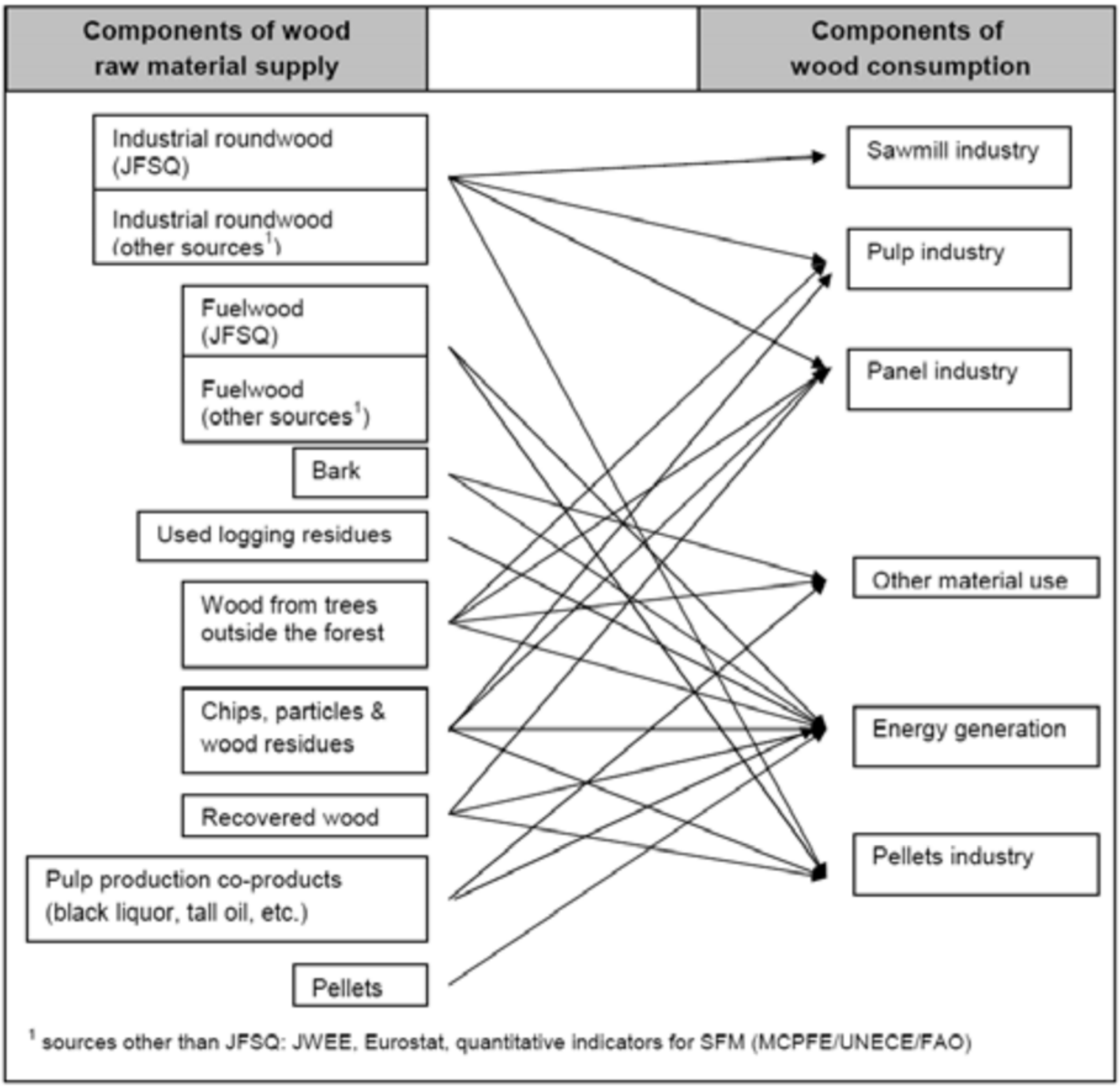


Figure 13 Model of cascading use of woody biomass (Steierer 2010)

The adjusted methodology applied for the Western Balkans countries was also applied by The Sector Study on Biomass-based Heating in the Western Balkans", World Bank, 2016.

The apparent consumption of production and consumption for different wood products in the Western Balkans countries was determined as follows:

Analysis of woody biomass use for the region as a whole and individually by countries is conducted by using the balancing method according to the UNECE methodology based on the so called cascading use of biomass (Figure 13). Cascading use of biomass implies "the same biogenic resources are used sequentially: first (and possibly repeatedly) for material applications and then for subsequent energy applications." [UNECE/FAO 2014]

Wood resource balances are based on available production and trade statistics which are in addition supplemented by a sector specific consumption analysis.

Analysis of current production and use of woody biomass in particularly country included:

- Analysis of registered production and actual consumption of woody biomass for selected year and
- Analysis of actual consumption of woody biomass compared to total available technical potentials for energy, industry and other purposes.

Objective of the first approach was to observe the structure of production and consumption, share of certain exports in total production as well as the share of certain consumer categories in total consumption of woody biomass. Differences between actual consumption and registered production resulting from calculations represent unregistered production.

Objective of the second approach was to observe to what extent the existing available potentials are already used for different purposes and what amount of woody biomass remains unused. It was starting point for estimation of production and consumption of different wood products.

To determine the **user defined potential 1** from saw mills the part of the residues that is utilised for board and pulp production is deduced. Thee deduction factor applied is based on data on the wood flow in Germany and Austria, for the other countries a factor in between the values for Germany and Austria is applied.

Table 40 Deduction factor to account for residues that are utilised in paper and board production,

Country	Share	Source
Austria	59 %	Value is based on data for Austria from Klima activ (2014a & 2014b)
Germany	46%	66% is the average of annual values determined for Germany for 2010-2014 using data from CEPI, Germany (2014) and CEPI, Germany, (2012).
Other countries	50%	Average share of CEPI countries & members determined using data from CEPI (2014).

2.7.2.3 Secondary residues from semi-finished wood based panels

The analysis of residues from semi-finished wood based panels follows the categories established by FAOSTAT (Table 41).

Table 41 Overview and definition of semi-finished wood based panels

Type	Definition
Particle board	A panel manufactured from small pieces of wood or other ligno-cellulosic materials (e.g. chips, flakes, splinters, strands, shreds, shives, etc.) bonded together by the use of an organic binder together with one or more of the following agents: heat, pressure, humidity, a catalyst, etc. The particle board category is an aggregate category. **It includes** oriented strandboard (OSB), waferboard and flaxboard. **It excludes** wood wool and other particle boards bonded together with inorganic binders. **It is reported in** cubic metres solid volume.

Type	Definition
Fibreboard *includes:*	A panel manufactured from fibres of wood or other ligno-cellulosic materials with the primary bond deriving from the felting of the fibres and their inherent adhesive properties (although bonding materials and/or additives may be added in the manufacturing process). **It includes** fibreboard panels that are flat-pressed and moulded fibreboard products. **It is an aggregate comprising** hardboard, medium density fibreboard (MDF) and other fibreboard. **It is reported in** cubic metres solid volume.
-MDF	*Dry-process fibreboard. When density exceeds 0.8 g/cm3, it may also be referred to as "high-density fibreboard"(HDF).* ***It is reported in*** *cubic metres solid volume*
- Hardboard	*Wet-process fibreboard of a density exceeding 0.8 g/cm3.* ***It excludes*** *similar products made from pieces of wood, wood flour or other ligno-cellulosic material where additional binders are required to make the panel; and panels made of gypsum or other mineral material.* ***It is reported in*** *cubic metres solid volume.*
- Insulating board	*Wet-process fibreboard of a density not exceeding 0.8 g/cm3. This includes mediumboard and softboard (also known as insulating board).* ***It is reported in*** *cubic metres solid volume.*
Veneer	Thin sheets of wood of uniform thickness, not exceeding 6 mm, rotary cut (i.e. peeled), sliced or sawn. **It includes** wood used for the manufacture of laminated construction material, furniture, veneer containers, etc. **Production statistics should exclude** veneer sheets used for plywood production within the same country. **It is reported in** cubic metres solid volume.
Plywood	A panel consisting of an assembly of veneer sheets bonded together with the direction of the grain in alternate plies generally at right angles. The veneer sheets are usually placed symmetrically on both sides of a central ply or core that may itself be made from a veneer sheet or another material. **It includes** *veneer plywood* (plywood manufactured by bonding together more than two veneer sheets, where the grain of alternate veneer sheets is crossed, generally at right angles); *core plywood* or *blockboard* (plywood with a solid core (i.e. the central layer, generally thicker than the other plies) that consists of narrow boards, blocks or strips of wood placed side by side, which may or may not be glued together); *cellular board* (plywood with a core of cellular construction); and *composite plywood* (plywood with the core or certain layers made of material other than solid wood or veneers). **It excludes** laminated construction materials (e.g. glulam), where the grain of the veneer sheets generally runs in the same direction. **It is reported in** cubic metres solid volume. Non-coniferous (tropical) plywood is defined as having at least one face sheet of non-coniferous (tropical) wood.

Source: Forest product definitions by FAOSTAT.

Secondary residues from semi-finished wood based panels are determined using production data from FAOSTAT, shares of residues per input quantity and a factor that relates round wood input quantities to product quantities as provided by UNECE/FAO (2010) and Saal (2010a) using:

$$\text{Res-Q} = \text{SBP\%} * \text{P-Q} * \text{IPF}$$

Where

Res-Q: Quantity of residues;

P-Q: Product quantity,

IPF Round wood input to product factor

SBP% Share of wood residues per m³ round wood input

For the current potential "2012" the FAOSTAT production data from 2010 to 2014 have been used to determine an average value in order to reduce the influence of annual market fluctuations.

Since only view country specific factors are available, average values are used for all countries (see Table 42).

Table 42 Factors used to determined secondary residues from semi-finished wood based panels

Product category	Share of wood residues per m³ round wood input [%] (Saal 2010a)	Factor m³ round wood input / m³ product (UNECE FAO 2010, Saal 2010a)
Particle board	3.94	1.51
OSB	9.80	1.63
MDF	9.61	1.68
Hardboard	11.61	2.03
Insulating board	4.57	0.83
Veneer / plywood	45.00	1.87

Since the approach used is referring to the average round wood input, the fact that residues are reused within the board industry, the resulting quantities that result are at the same time the **technical and the base potential.**

For the Western Balkans countries Montenegro, FYROM, Albania, Bosnia and Herzegovina, Serbia, Kosovo and Croatia the same ratios as given in table 10 is used. However, for determination of the quantity of semi-finished wood based panels produced, the same equation as in the case of sawnwood is used.

Due to lack of reliable data on production and consumption of semi-finished wood based panels for the Western Balkans countries it is necessary to use the following formulae for calculation of P-Q (product quantity) based on national level data sources.

P-Q= AC – I + E

AC-apparent consumption

I - import

E- Export

The adjusted methodology applied for the Western Balkans countries was also applied by ''The Sector Study on Biomass-based Heating in the Western Balkans'', World Bank, 2016.

For the database all boardtypes are totalled up, the average shares of these totals are given in Table 43, obviously plywood and veneer have the largest share.

Table 43 Residues shares per board type in S2BIOM Countries

Hardboard	*Insulating board*	*MDF*	Particle board	Plywood	Veneer
5,1%	0,6%	13,6%	13,3%	40,7%	26,7%

Source: Own calculations.

2.7.2.4 Secondary residues from further processing

Following an approach developed by Saal (2010a) residues from further processing are determined for the 4 business sectors "Construction", "Packaging", "Furniture" and "Other" using

SBP-Q = Res% *N-E * EF

Where

Res% = Residues per round wood input

N-E No of employees per sector

EF Expansion factor Wood consumption / employee

For these sectors EUROSTAT provides data on employees by for production sector in their section on structural business statistics using the classification system “European industrial activity classification (NACE)” that is adopted from time to time in specific versions.

For the current potential “2012” the EUROSTAT employee statistical data published for 2012 have been used.

Saal (2010a) had used the NACE Rev 1.1 classification that was changed in 2009 to NACE 2 (see Table 44).

Table 44 Business sub-sectors from structural business statistics utilised to determine the number of employees for the estimation of the residues from further processing

	NACE 1 Rev. 1.1	NACE 2
Construction	20,3	16,22; 16,23
Packaging	20,4	16,24
Other	20,51	16,29
Furniture	36,11; 36,12; 36,13, 36,14	31,01; 31,02, 31,09

Following the approach of Saal (2010a, 2010b) a relation between the number of employees and the amount of consumed wood products per sector that was determined using data on these sectors in Germany (Mantau &Bilitevski, 2010). Using the data from Mantau &Bilitevski (2010) the factors have been adjusted for the new NACE 2 classification system. The adjustment is based on statistics from 2007 and from 2008, where data based on both classification systems have been available.

The factors used to determine secondary residues from further processing are presented in Table 45.

Table 45 Factors used to determined secondary residues from further processing

Sector	**Wood consumption [m³] per employee** (Own calculation using empirical data from Mantau & Bilitewski, 2010)	**Residues shares** (Mantau & Bilitewski, 2010, Saal 2010a)
Construction	311.8	10.3%
Furniture	79.4	18.4%
Packaging	540.1	9.7%
Other	117.5	13.0%

EUROSTAT does not provide data on employees for Ukraine, Moldavia, Montenegro, FYROM, Albania, Bosnia and Herzegovina, Serbia and Kosovo. For these countries national level statistics have been used.

Regional specific values for the Wood consumption [m³] per employee have been determined for the Western Balkans countries Montenegro, FYROM, Albania, Bosnia and Herzegovina, Serbia, Kosovo and Croatia. For these countries estimates of the wood consumption of all sectors per employee the following data have been used:

1. The total wood consumption (sawnwood +wood based panels) on country level using national and FAO statistics.
2. The total number of employees in these 4 sectors using national statistics as well as EUROSTAT for those countries for which the EUROSTAT contains data.

This resulted in the country wise factors presented in Table 46.

Table 46 Wood consumption [m³] per employee in Western Balkan countries

Country	Wood consumption [m³] per employee
Kosovo	72.4
Montenegro	98.4
Albania	89.7
Bosnia and Herzegovina	119.9
Croatia	57.1
FYROM	46.2
Serbia	88.7

The residue share as for the EU countries have been utilised. The general principle of the calculation is the same as in the case of the EU 27 countries, so the comparability of the data is secured.

Since the approach used is referring to the average round wood input, the fact that residues are reused within this sector or the board industry or the pulp industry, the resulting quantities that result are at the same time the **technical and the base potential.**

2.7.2.5 Residues from pulp and paper

Secondary residues from semi-finished wood based panels are determined using production data from FAOSTAT per pulping technology, shares of residues per input quantity and a factor that relates round wood input quantities to product quantities.

For the current potential "2012" the FAOSTAT production data from 2010 to 2014 have been used to determine an average value in order to reduce the influence of annual market fluctuations.

In a first step the round wood input per pulp technology is estimated using

RWE input = P * C

P Pulp in tones

C Conversion factor RW Input per ton

With conversion factors published by UNECE /FAO (2010) (Table 47)

Table 47 Conversion factor round wood input / ton pulp

Pulp type	Conversion factor [m3 wood input / ton pulp [dmt = air dried]
Mechanical	2.50
Semi-chemical	2.67
Chemical	4.49

According to Smook (1992) approximately 40-50% of the input raw material can be recovered as usable fibre.

To estimate the amount of black liquor from the chemical pulping process a factor of 0.5 is thus adequate to determine the amount of round wood input that is included in the pulp that contains in addition chemicals that are used to separate cellulose from lignin (Saal 2010a).

To estimate the amount of bark the following formula was used

B = RWE-I * F-share * B-factor

B - Bark volume

RWE-I - Round wood input [m3]

F-share - Share of wood from forests

B-Factor - Bark in relation to round wood

We used a factor for bark in relation to RWE of 10% considering an average over bark/ under bark ratio of 0.88 (UNECE/FAO 2010) and certain bark losses. Debarking in the forest is regarded negligible.

Bark residues result from debarking wood originating from round wood. Since both, residues from saw mills and round wood is used by the pulp and paper industry the share of wood from forests used in the pulp industry per countries is determining the amount of bark residues.

The shares per country have been determined using available industry statistics (Table 48).

Table 48 Share of round wood in the pulp and paper industry

Country	Share	Source
Austria	53.7 %	Value is based on data for Austria from Klima activ (2014a & 2014b).
Finland & Sweden	80.1%	Value is based on data for Finland from Heinimö & Alakangas (2011).
Germany	66.0%	66% is the average of annual values determined for Germany for 2010-2014 using data from CEPI, Germany (2014) and CEPI, Germany (2012).
Other countries	75.0 %	Average share of CEPI countries & members determined using data from CEPI (2014).

These potentials determined are at the same time the **technical and the base potential.**

2.7.2.6 Spatial disaggregation

In order to estimate the amount of residues available per Nuts 3 region attributes respectively data that are available *and* assumed to best explain the spatial distribution of the respective residues have been used for allocation inside a country that is proportional to the explanatory attribute. The approach utilised per category is provided inTable 49.

Table 49 Spatial disaggregation approach by sector

Category, category group	Approach
Saw mill residues, conifers	Forest cover of conifer forests using the Copernicus high resolution forest type layer of Europe.
Saw mill residues, non-conifers	Forest cover of broad leave forests using the Copernicus high resolution forest type layer of Europe.
Residues from industries producing semi -finished wood based panels	*National level to Nuts 2:* Employees of the wood industry sector retrieved from EUROSTAT. Nuts 2 to Nuts 3: Land area.
Residues from further wood processing	*National level to Nuts 2:* Employees per sector "Construction", "Furniture", "Packaging", "Other" retrieved from EUROSTAT applied on residues of the respective sectors. Nuts 2 to Nuts 3: Land area
Secondary residues from pulp and paper industry	Number of pulp and paper mills per NUTS3 area.

For Ukraine the data in forest cover by species groups were taken from national level statistics.

The spatial data sets have been prepared as follows:

The Copernicus high resolution forest type layer of Europe.

The high resolution (20m) forest type layer of the Copernicus Land Monitoring Services was used as main data source for the calculation of the forest areas per NUTS3, NUTS2, and country level. The forest types layers distinguishes between forests dominated by coniferous species and those dominated by broadleaved species and follows the FAO forest definition with a minimum mapping unit of 0.5 ha and a 10% tree cover density threshold.

As it can be seen from the "High Resolution Forest Type Map of Europe 2012" which a visualization of the high resolution forest type layer, there are considerable areas which were not classified especially in Scandinavia and further the data does not cover Moldova and Ukraine. These gaps were filled using the following approach:

Official forest area statistics were used to determine the forest areas for both coniferous and broadleaved forests in Ukraine[7] and Moldova[8]. Further the unclassifiable areas of the high resolution forest type layer were supplemented by the Pan-European Forest Type Map 2006 from the Joint Research Centre of the European Commission resulting in a forest type layer without classification gaps as shown in the "Supplemented High Resolution Forest Type Map of Europe".

Detailed information on the Copernicus forest high resolution layers as well as data visualisation and data download capability is provided at http://land.copernicus.eu/pan-european/high-resolution-layers/forests/view (accessed 18th January 2016).

The resulting maps are shown in Figure 14.

[7] Ukrainian forests handbook. Published in 2012 by State Agency of forest resources of Ukraine on the materials of forests accounting in 2010.

[8] http://statbank.statistica.md/pxweb/Dialog/varval.asp?ma=GEO0502_en&ti=Main+indicators+of+the+forest+fund %2C+2005%2D2014&path=../Database/EN/01%20GEO/GEO05/&lang=3

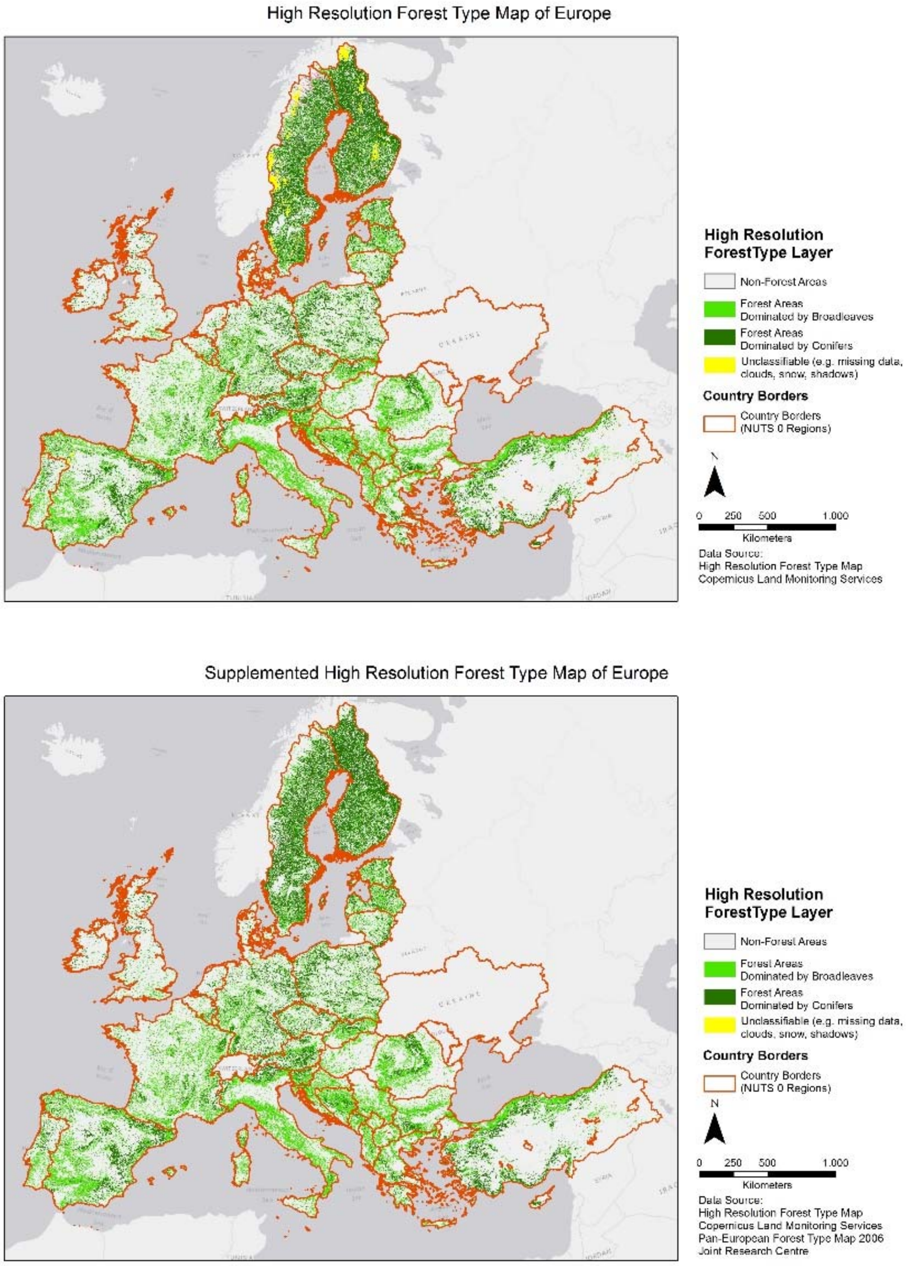


Figure 14 Copernicus high resolution forest type layer 2012 of Europe and corresponding gap filled layer

Locations of pulp and paper mills in Europe

The spatial data on the locations of pulp and paper mills in Europe have been retrieved using a map received from the European pulp and paper association CEPI. The resulting NUTS 3 distribution is visualized in Figure 15.

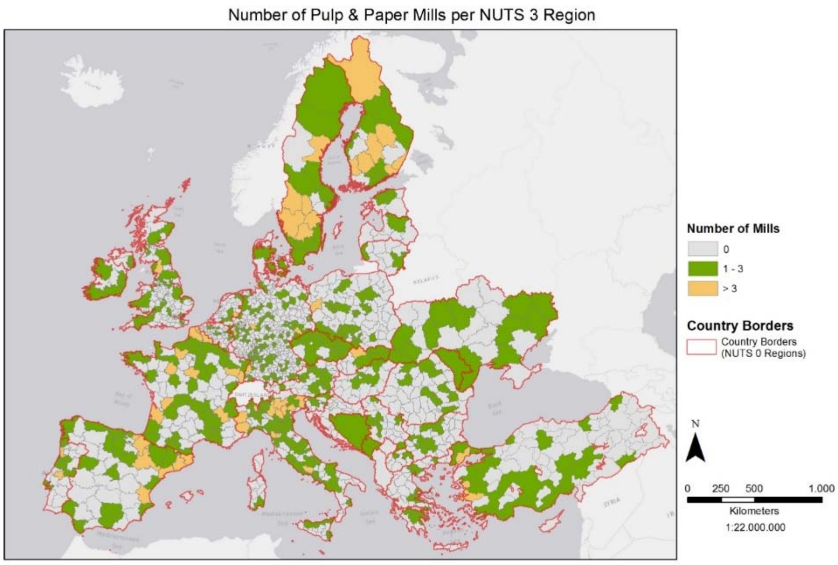


Figure 15 Distribution of pulp and paper mills in Europe.

Data on population totals per NUTS3

The data on population per NUTS3 area are taken from Eurostat (2012) and have been complemented by national level data. The resulting NUTS 3 distribution is visualized in Figure 16.

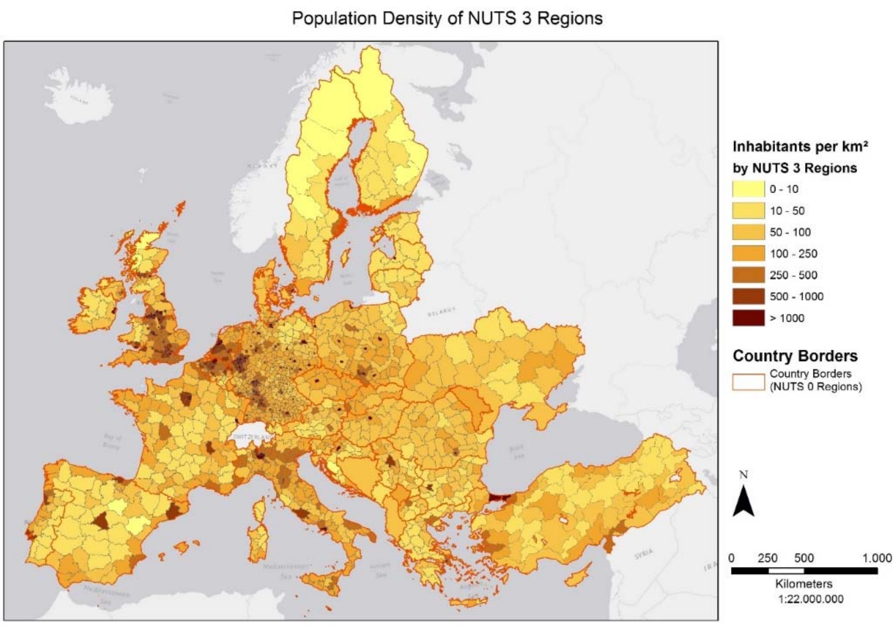


Figure 16 Population density per NUTS3 area

2.7.2.7 Methods used to estimate potentials for 2020 and 2030

The EU-Wood study (Mantau et al. 2010) projects the demand for material use without considering competition with other sectors in order to explore if the increasing demand for energy will lead to a strong competitive situation where the demand substantially exceeds the supply. The EU-Wood project (Mantau et al. 2010) has aligned the prediction of the future demand to the real GDP (Gross domestic product) and thus the prediction that utilises the IPCC B2 scenario assumptions shows a strong increase (see Figure 17).

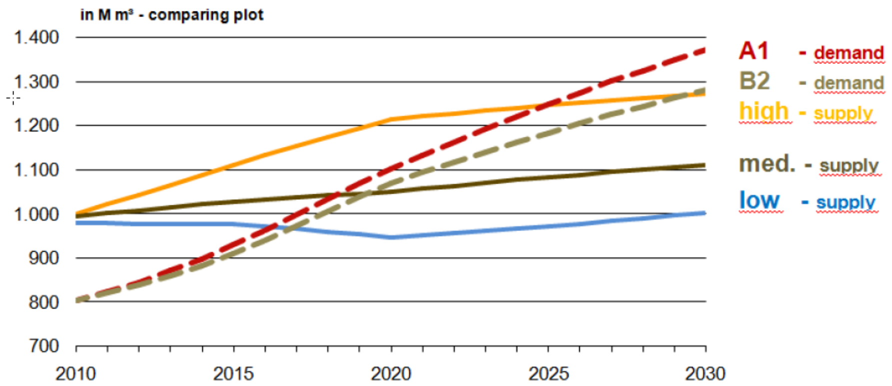


Figure 1-4: Development woody biomass potential demand and potential supply

Source: EUwood 2010

Figure 17 Future development of demand and supply as projected by the EU-Wood project for different scenarios (Mantau et al. 2010)

Thus, to constrain the potentials by such demand projection would constrain the potential with strong preference to material use. The recent trends of the forest products consumption index indicate that the production has changed its relation to the GDP (seeFigure 18).

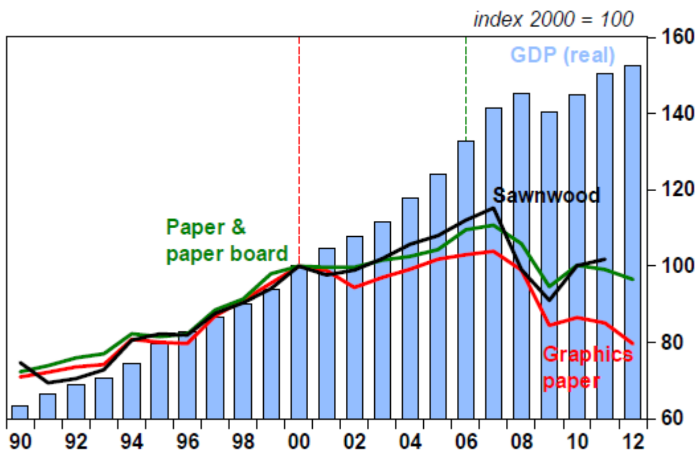


Figure 2.1.2. EU GDP (real) and forest products consumption index over the period 1990-2012 (2000 = 100). (Forest products data from FAO; GDP data from IMF, Gross domestic product based on purchasing-power-parity (PPP) valuation of country GDP).

Figure 18 EU GDP and forest products consumption index[9]

[9] Source: Birger Solberg, Lauri Hetemäki, A. Maarit I. Kallio, Alexander Moiseyev and Hanne K. Sjølie (2015) Impacts of forest bioenergy and policies on the forest sector markets in Europe – what do we know?

An alternative to use predict the future industry production results from modelling that considers economic competition. Such estimates and are available from the EFSOS II study for 2010, 2020 and 2030. The trends of the EFSOS II study are utilised by S2BIOM. Figure 19 and Figure 20 show for swan wood and panels that the S2BIOM data for 2012 are close to EFOS II reference scenario projections 2010.

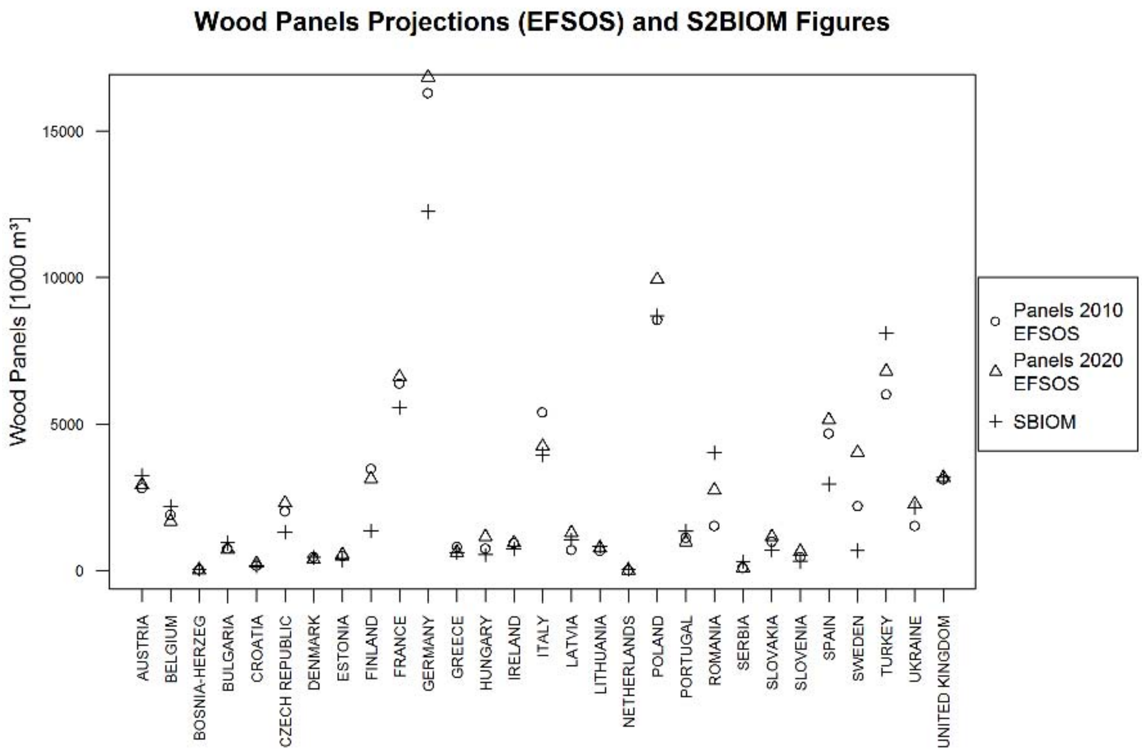


Figure 19 Wood panel production, EFSOS 2 reference scenario projections, and S2BIOM 2012 estimates

The S2BIOM residue and production figures of the timber industry were thus projected to the years 2020 and 2030 using the growth rates of the reference scenario of the UNECE European Forest Sector Outlook Study II (EFSOS II) for sawnwood and wood based panel production.

For the pulp and paper sector there was a huge difference between S2BIOM 2012 quantities and the EFOS reference scenario projections.

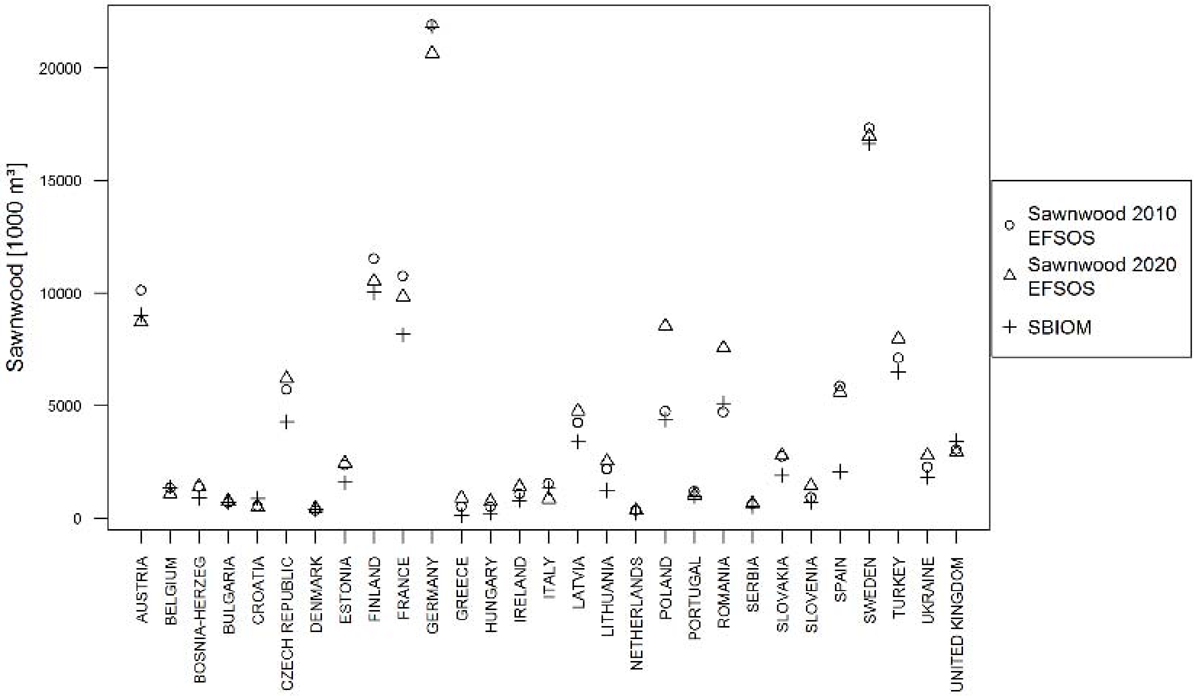


Figure 20 Sawnwood production, EFSOS 2 reference scenario projections and S2BIOM 2012 estimates

The visualisation of the figures from the “Historic Statistics” report of CEPI on pulp and paper production are shown in Figure 21. This figure shows the changes of pulp production for the CEPI member states which are: Austria, France, Netherlands, Romania, Sweden, Belgium, Germany, Norway, Slovak Republic United Kingdom, Czech Republic, Hungary, Poland, Slovenia, Finland, Italy, Portugal and Spain. It is for S2BIOM assumed that the changes in production after some bigger fluctuations in the past will be in 2020 and 2030 in the same dimension as in 2012. Hence the production quantities from 2012 are used for 2020 and 2030 as well.

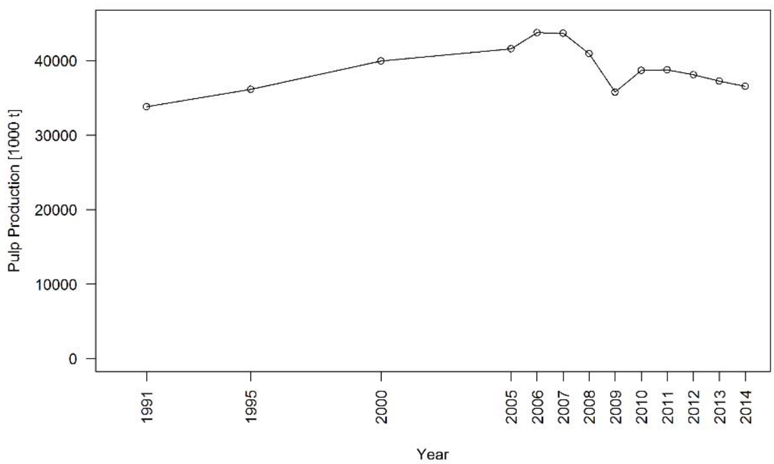


Figure 21 Development of Pulp production, CEPI data

The approach used is summarised by category in Table 50.

Table 50 Approach used to estimate future production amount in the wood industry

Sector	Approach
Saw mill residues, conifers	EFSOS II sawnwood, reference scenario
Saw mill residues, non-conifers	
Residues from industries producing semi -finished wood based panels	EFSOS II wood based panels production, reference scenario
Residues from further wood processing	EFSOS II sawnwood, reference scenario
Secondary residues from pulp and paper industry	No change vs. presence.

2.7.3 Methods to estimate costs

It is assumed that all costs that occur in the wood industry sector are motivated by the aim of producing the main product and that all residues, even if they have a market price and traded they are not regarded as by products but as residues that are of course still used in the most economical way, thus either traded or utilised for heat and power internally rather than regarded as waste and entered into the waste stream, which would be the costly alternative.

Thus for all SFR the costs are regarded as zero at mill/ production site road side.

2.8 Secondary residues of industry utilising agricultural products

2.8.1 Overview of potential levels

All the secondary agricultural residues included in the potential calculation refer to residues of crops that are mostly grown and processed in the S2BIOM countries. Their assessment can therefore be based on production information (area and/or yield information) derived from national agricultural statistics.

Table 51 Subcategories of “42 Secondary residues of industry utilising agricultural products

Third level subcategories		Final level subcategories	
ID	Name	ID	Name
421	By-products and residues from food and fruit processing industry	4211	Olive-stones
		4213	Rice husk
		4214	Pressed grapes residues
		4215	Cereal bran

Only one potential type has been elaborated for this group of biomass types; which is the maximum available potential referred to as the technical potential. It is based on available agricultural statistical data on land area of the crops delivering the residue and/or yield levels of the main crop. So, the potential calculated refers to the technical potential. However, since there is no direct sustainability consideration that prescribes the need of returning (part of) the secondary residues to the soil, we assume that the base potential can be the same as the technical potential.

2.8.2 Methods to estimate the supply potential

For the calculation of the amounts of secondary residues produced, the total yield of the main crop is multiplied with a factor expressing the residue to yield factor (see Table 52., for cotton gin, rice husks, grape dreg and stalks and cereal bran).

Table 52 Specification on the secondary agricultural residue potential calculation approach

Biomass type	Potential assessed	Area / Source	Residue factor	Technical & environmental constraints	Consideration of competing use
Olive-stones	Technical potential = Base potential (except for olive pitts)	CAPRI & national statistics: Area with all olive trees (table=oil olives) 2012, 2020, 2030	Olive pitts make up between 10%-12.5% of the weight of olive according to Garcia et al. 2012 and Pattarra et al., 2010)	**Technical** = pitts from both oil and table olives **Base**= pitts from all oil olives + 30% of table olives	None
Rice husk		CAPRI & national statistics: Area with rice in Europe 2012, 2020, 2030	Rice husk is approximately 20% of the processed rice, with average moisture content of 10% ((Nikolaou, 2002)). It is assumed that all rice produced in the S2BIOM countrie is locally processed	None	None
Pressed grapes residues (pressing residues & stalks)		CAPRI & national statistics: Area with vineyards in Europe 2012, 2020, 2030	Of the processed grapes 4.6% consists of dregs and 1.5% of stalks (FABbiogas (2015), Italian country report)	None	None
Cereal bran		CAPRI total estimate of tons processed cereals per EU country	In wheat processing 20% to 25% wheat offals (Kent et al., 1994). Wheat bran represents roughly 50% of wheat offals and about 10 to 19% of the kernel, depending on the variety and milling process (WMC, 2008; Prikhodko et al., 2009; Hassan et al., 2008). . So the residue to yield factor used is 10% of cereals processed domestically.	None	None

The overall calculation of the technical potential of secondary residues follows the same general formula as for residues from rotational arable crops (see also Section 2.2.2):

RESIDUE_YIELDi = MAIN PRODUCT yieldi * RES_YIELDi ratio * DM_CONTENTi.

Where:

- RESIDUE_YIELDi = total residue yield of crop i in Ton/Year dry mass
- RES_YIELDi = Secondary residue yield Ton/Ha/Year in fresh mass of crop i
- DM_CONTENTi= Dry matter content of residue of crop i
- MAIN PRODUCT yieldi = this is the yield of the main product i which in the processing at the mill delivers the secondary by-product

For the calculation of the olive stones, rice husk and pressed grapes dregs we assumed that all domestic production would also be processed locally and that is no further processing of imported olives, rice and grapes. This implied that the residues would be available locally and that the regional distribution of the processing residues is a direct outcome of the cropping area distribution over regions in every country.

For cereal bran it is more logical to assume that the basis should be the total amount of cereals processed in every country. This implies that cereal bran needs to be calculated for a total net domestic cereal production and imports:

$$\textit{Domestic production}_{cereals} - \textit{export}_{cereals} + \textit{import}_{cereals}$$

The data on total domestic production, exports and imports levels were available from CAPRI for 2010 (extrapolated to 2012), 2020 and 2030 for all S2BIOM countries except for Ukraine.

To come to a regional distribution of the cereal bran potentials in every S2BIOM country 2 assumptions were made:

1) The bran based on the net domestic production (=domestic production – exports) is distributed regionally according to cereal production area share.
2) The cereal bran based on processing of imported biomass is distributed over largest (port) cities per country as it is expected that processing industries are there where imports enter the country and where population is concentrated. The residues were spatially distributed to regions with the large and medium sized cities (>100,000 inh.), every city was equally weighted.

For Ukraine, there were no CAPRI data available on domestic production of cereals, nor imports and exports. Instead we used data from the statistical yearbook "Agriculture of Ukraine" for 2013, Data of State Statistics Committee of Ukraine. This implied data were only available for one year. For the 2020 and 2030 situation the Ukraine potential is assumed to be stable.

2.8.3 Methods to estimate costs

The approach to cost for secondary residues from agriculture is similar to that of the secondary residues from forest. This implies that cost at the processing installation are set at '0'. This is because cost of processing are allocated fully to the main product. However, this does not imply that there is no market price for these products. In most cases, these side products still have large value at the market because there is large demand for it for different uses such as animal feed.

2.9 Waste collection/ tertiary residues

2.9.1 Overview of potential levels

An overview on the potential levels is provided in Table 53 .

Table 53 Subcategories of first level category 1 "Waste"

Second level subcategories		Third level subcategories		Final level subcategories	
ID	Name	ID	Name	ID	Name
51	Biodegradable municipal waste	511	Biowaste	5111	Biowaste as part of integrally collected municipal waste: Biodegradable waste of not separately collected municipal waste (excluding textile and paper)
				5112	Separately collected biowaste: Biodegradable waste of separately collected municipal waste (excluding textile and paper)
52	Post-consumer wood	512	Post-consumer wood	5211	Hazardous post-consumer wood
				5212	Non-hazardous post-consumer wood

<u>Technical potential</u>

The Technical potential represents the amount of biomass assuming only technical constraints and a minimum of constraints by competing uses.

In case of biowaste no constraints are considered in the technical potential.

In case of post-consumer wood, the technical potential assumes that 5% of all wood waste cannot be recovered and used for energy application for technical reasons. Competing uses (current material application of the wood) are not taken into account.

<u>Base potential</u>

This is the sustainable technical potential, considering currently agreed sustainability standards.

In case of biowaste the base potential equals the technical potential.

In case of post-consumer wood, the base potential takes into account the current material application of recovered wood, and assumes that this material application remains constant in 2020 and 2030

<u>User defined potential</u>

The user-defined potentials vary in terms of type and number of considerations per biomass type. The user can choose the type of biomass and the considerations he would like to add and calculate the respective potential. This flexibility is meant to help the user to understand the effect on the total biomass potential of one type of consideration against the other.

In case of biowaste no user-defined potentials have been developed.

In case of post-consumer wood, one user-defined potential has been developed. This user defined potential on cascading use of post-consumer wood takes into account the current material application of post-consumer wood in 2012, and assumes that the material application of non-hazardous post-consumer wood will increase to 49.2% in 2020 and 61.5% in 2030 (See Table 54), or remain stable if current (2012) material use is higher.

Table 54 assumed material consumption of non-hazardous post-consumer wood in user defined potential.

	Technical potential 2012 (EU28) (mln. m^3)	target 2020	target 2030
Packaging wood	24.011 (45.9%)[a)]	60%	75%
Other (construction, household waste wood)	28.328 m^3 (54.1%)[b)]	40%	50%
Resulting material consumption UD1		49.2%	61.5%

[a)] Eurostat, database code env_waspac, converted from mass to volume by factor 2 m^2/tonne. [b)] Based on total potential as estimated in this study (based on EU Wood and EFSOS II) minus packaging wood as provided by Eurostat.

The Circular Economy Package[10] proposes a target of 75% of material recycling of packaging wood in 2030, this will be a challenge but the quality of packaging waste (mainly clean sawn wood) is suitable for recycling. The other waste wood fractions are more difficult to recycle; there are not too many options to recycle used panels (particleboard, MDF, OSB, plywood). Recycling rates of other wood (besides packaging) are not expected to exceed 40% in 2020 and 50% in 2030. Based on the share of packaging wood/non packaging post-consumer wood in 2012, this results in an overall assumed material application of non hazardous post-consumer wood of 49.2% in 2020 and 61.5% in 2030. All wood classified as hazardous waste will remain available for energy generation as the recycling options for these types of wood are limited.

2.9.2 Methods to estimate the supply potential

2.9.2.1 Introduction

This chapter deals with the methods to estimate the potentials of biowaste and post-consumer wood.

The possibilities to use biowaste depend on the collection methods that are in place, which differs per country. Biowaste can be separately collected and used for

[10] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL amending Directive 94/62/EC on packaging and packaging waste COM/2015/0596 final

composting with or without an anaerobic digestion step; biowaste as part of municipal waste can be incinerated with energy recovery, or combusted after a mechanical biological treatment (MBT) step.

Post-consumer wood is a secondary raw material, which should be collected, sorted and re-utilized or recycled, including as biomass for energy production. Despite a considerable rise in the collection and utilization rates - particularly recycling, post-consumer wood is a resource, which is still underutilized in many European countries. As a first step towards increased recovery and re-utilization, more information is necessary about the potential quantities of recoverable wood as well as to what extent these sources can be sustainably re-utilized or recycled at national and European levels.

2.9.2.2 Methodology for biowaste

Definition

Biowaste is defined in the Waste Framework Directive (2008/98/EC) as "biodegradable garden and park waste, food and kitchen waste from households, restaurants, catering and retail premises and comparable waste from food processing plants". Biowaste is part of biodegradable municipal waste, defined in the EU Landfill Directive (1999/31/EC) as "any waste that is capable of undergoing anaerobic or aerobic decomposition, such as food and garden waste and paper and paperboard". Biodegradable municipal waste includes separately collected paper and paper board, which is not relevant for bioenergy production as this fraction should be used for material reuse. Therefore, in S2BIOM we will focus on the availability of biowaste.

Calculation method

The availability of biowaste in 2012 on NUTS3 level was established as:

MSW generated per capita (kg/capita) x

biowaste fraction (%) x

population of the NUTS3 area (persons).

A further distinction has been made between the separately collected biowaste and biowaste as part of mixed waste.

MSW per capita

European statistics provide information on the amounts of Municipal solid waste generated per capita in a country. (see Municipal waste generation and treatment, by type of treatment method, code tsdpc240,

http://epp.eurostat.ec.europa.eu/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=tsdpc240).

The data is available on country level (NUTS0). It is likely that differences exist in quantities of MSW per capita between regions and that the composition differs between urban and rural areas, etc. Eurostat has carried out a pilot on collection data on Municipal waste per capita by NUTS 2 regions (See Municipal waste by NUTS 2 regions - pilot project, Eurostat code: env_rwas_gen). The project covered, however, a limited number of countries and data collection seems to have stopped after 2011. Therefore NUTS0 MSW per capita data will be used.

Biowaste fraction

Eurostat does not publish data on the share of biodegradable waste or biowaste within municipal solid waste. This ratio has to be collected from statistical information and sorting analyses on national level. Arcadis and Eunomia (2010)[11] have analysed literature on the share of biowaste in household waste in all the EU27 countries. In case no data could be found for a particular country, the study used the share of biodegradable municipal waste in municipal waste that is known for the year 1995 because of the implementation of the Landfill directive multiplied with a factor of 56% biowaste in biodegradable municipal waste. The latter factor is based on composition of household waste in Pleven and Flanders and the assumption that total biodegradable waste consists of biowaste + paper + textiles + ½ of other fractions. The biowaste fractions established in Arcadis and Eunomia (2010) are used in S2BIOM WP1 as it forms the most up to date complete set of biowaste fractions for the EU27 currently available. For Croatia (the 28th EU country) BTG has assumed that the biowaste fraction is the average fraction of neighbouring countries Slovenia and Hungary. For the non-EU countries, no data on the biowaste fraction has been collected, instead the average biowaste fraction of 35.9% as established in Arcadis and Eunomia has been used.

Population data

For the base year 2012 population data on NUTS3 level was taken from Eurostat (code demo_r_gind3).

Separately collected biowaste versus biowaste in mixed waste

Arcadis and Eunomia (2010) have analysed the percentages of biowaste that is collected separately or exist as part of mixed waste for the EU27 on country level. These numbers (base year 2008) have been used in our assessment.

Projection of potentials to 2020 and 2030

In Arcadis and Eunomia (2010) projections have been provided of the shares of biowaste going to the different treatment options like landfill, incineration, MBT, composting, backyard composting, anaerobic digestion and others have been made for the years 2008-2020. It has been assumed that all countries meet the requirement of the landfill directive, e.g. that maximally 35% of the amount of biodegradable waste

[11] Arcadis and Eunomia (2010) Assessment of the options to improve the management of bio-waste in the European Union - final report, Version C 12-02-2010. Study contract Nr. 07.0307/2008/517621/ETU/G4, European Commission, DG Environment.

generated in base year 1995 is landfilled in 2020, even if current developments show that diversion from landfill has not been successful yet. Furthermore, the projections are based on policy views and current changes in treatment of biowaste in the member state concerned. For instance, some countries have a strong preference for MBT, others for incineration with energy recovery. For the year 2030 the same shares between treatment options are used as in the year 2020. Currently no policies are known that influence the production of biowaste after 2030, therefore it is assumed that the projected status quo in 2020 will be maintained in 2030.

Projections on the development of the total quantity of biowaste are assumed to be proportional to population growth. The main scenario on population development from Eurostat has been used to predict the population in 2020 (Eurostat code proj_13npms). This information is only available on country level (NUTS0). In order to establish population data in 2020 and 2030 the NUTS3 level population data of 2012 has been multiplied with the expected change in population in 2020 and 2030 compared to 2012 on national level. This ignores the fact that some regions will grow or decrease more than the national average rate, leading to a possible error in estimation of biowaste production in the order of 0-10%.

The development of biowaste has not been linked to GDP growth, given the uncertainty of GDP development and the fact that many EU countries will reach or have reached decoupling with GDP. This is a conservative assumption, especially for European countries with still a relatively low GDP.

Conversion factors

The following table summarises conversion factors that have been used to convert the mass to volumes and energy. The data is retrieved from the biomass properties database developed in WP2 of S2BIOM

	NVC_{ar} MJ/kg	Moisture content ($w\%_{ar}$)	Basic density kg/m^3
5.1.1.1 Biowaste as part of integrally collected municipal waste: Biodegradable waste of not separately collected municipal waste (excluding textile and paper)	10.8	27.2%	500
5.1.1.2 Separately collected biowaste: Biodegradable waste of separately collected municipal waste (excluding textile and paper)	4.3	55.6%	500

2.9.2.3 Methodology for post-consumer wood

Definition

There are different definitions of post-consumer wood, recovered wood, etc. According to the COST Action 31 (Jungmeier, 2005)[12], recovered wood includes all kind of wooden material that is available at the end of its use as a wooden product (" post consumer" or " post-use" wood). In the EUwood project (Mantau et al 2010)[13], a slightly different definition is used: Post-consumer wood (PCW) includes all kinds of wooden material that is available at the end of its use as a wooden product ("post-consumer" or "post-use" wood). Post-consumer recovered wood mainly comprises packaging materials, demolition wood, and timber from building sites and fractions of used wood from residential (municipal waste), industrial and commercial activities. This definition is used in the current study as well.

Calculation method

$PCW_{technical\ potential} = PCW_{material} + PCW_{energy} + PCW_{disposed}$
$PCW_{base\ potential} = PCW_{energy} + PCW_{disposed}$

in which:

$PCW_{recovered}$ = PCW used for materials like panels and chipboards
PCW_{energy} = PCW used for energy production
$PCW_{disposed}$ = landfilled and/or incinerated with MSW.

Data collection

Eurostat gives data on "wood waste", but this includes not only post-consumer wood but processing wastes from agriculture forestry and fishing sectors. Because of this mixture of secondary wood processing and tertiary post-consumer wood within one category, Eurostat data could not be used to determine the potential of post-consumer wood. For this study, data on recovered wood were used from a forest biomass resource assessment done for the EUwood and EFSOS II studies (Mantau et al. 2010; UN-ECE/FAO 2011[14]). EUwood combines among others Eurostat and COST Action E31 data. The EFSOS II data on demolition wood is based on EU wood, but covers Europe as a whole instead of EU28. In order to determine the base potential PCW available for energy, it is necessary to estimate how much is used for

[12] Gerfried Jungmeier, Joanneum, Cost Action E31, Management of recovered wood, training course Hamburg, June 2005
[13] Mantau U et.al.; EUwood, Real potential for changes in growth and use of EU forests, Methodology report June 2010
[14] UNECE (United Nations Economic Commission for Europe), FAO (Food and Agricultural Organization of the United Nations) 2011: The European Forest Sector Outlook Study II; Geneva

material applications. In the Methodology report of the EUwood project[15], a table is given on the availability of *PCW recovered* [for material recycling] and *PCW energy* for 2007, page 119-120, which have been used in this study as well.

Data collection in non-EU28 countries

EFSOS II data has been used to estimate the availability of PCW in other European countries, as the EUwood study was limited to EU27. The fractions of used PCW for energy or material recovery are not known. Therefore, the EU28 data on these fractions as found in the methodology report of EUwood has been divided into five EFSOS regions in order to determine average values for these EFSOS regions. See Figure 22 for the overview of EFSOS II regions and Table 55 for the results. Subsequently, these average values have been used for the individual countries outside the EU that belong to these EFSOS regions.

Table 55 Assumed division between energy use and material use of the used fractions of post-consumer wood in the different EFSOS regions.

EFSOS regions	Energy use	Material use
North Europe	33%	67%
Central-West Europe	31%	69%
Central-East Europe	25%	75%
South West Europe	14%	86%
South East Europe	26%	74%

This approach results in a rough estimation of the use of post-consumer wood in the non-EU28 countries.

Distinction between hazardous versus non-hazardous wood

Eurostat differs between hazardous and non-hazardous wood, but unfortunately does not have a separate category for post-consumer wood, but includes also processing wastes from agriculture, forestry and fishing sectors as part of wood waste. In some countries like Netherlands and Germany, the shares of hazardous and non-hazardous post-consumer wood have been estimated, and are partly available in national statistics. These data have been used to estimate the share of hazardous post-consumer wood in the other countries.

[15] EU Wood (2010) Methodology report, real potential for changes in growth and use of EU forests EUwood. Call for tenders No. TREN/D2/491-2008.

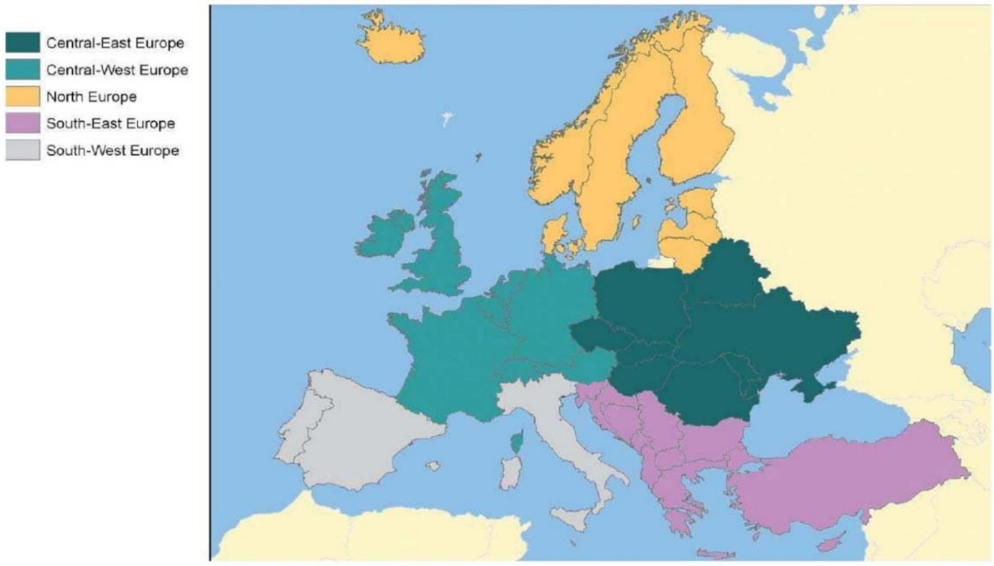


Figure 22 Overview of EFSOS II regions. Source: EFSOS II 2010-2030 Country profiles.

According to Probos (2014)[16] in the Netherlands yearly around 1000-1400 ktonnes A/B wood and 80-120 ktonnes/year of hazardous C-wood[17] is produced in the period 2007-2012. This means that C-wood counts for 7.6% (7.4-7.8%) of total post consumer waste. This number has been used in this study. For validation of this number the statistics on A/B-quality wood and C-quality wood in household waste can be used, which is available even on NUTS3 level. On average municipalities that registered both non-hazardous A/B-wood and hazardous C-wood, collected on average a share of 11% C-wood in 2012[18]. However, please note that household waste contains only 33% of the total post-consumer waste quantities[19]. According to a dedicated case study in the Bioxchange project, in Germany 17% of the PCW is

[16] De markt van resthout en gebruikt hout in 2012, Bosberichten 2014-04 (in Dutch)

[17] Three main categories of post-consumer wood can be distinguished, following the Dutch national Land Use Plan[17]: A-quality: unpainted and untreated wood; B-quality: wood not mentioned under A-wood and C-wood: among others painted, lacquered and glued wood. A-quality wood can be recycled or used for material recycling. B-quality wood can be used for both applications as well, given that certain treatment is provided (removing paint) or emission reduction equipment. A- and B-quality wood are often provided as mixtures, therefore it is not possible to distinguish between both categories in statistics. Both qualities will be indicated as non-hazardous wood. C-quality (hazardous) consists of treated wood like: Wood treated with creosotes, wood treated with wood preservatives containing copper, chrome and arsenic (CC and CCA wood), wood treated with other means (fungicides, insecticides, etc.).C-wood is a distinct category, in general not suitable for material recycling (with the exception of material reuse of creosoted wood), but in general[17] this wood can be combusted for energy generation, provided that sufficient measures are taken, especially advanced emission reduction measures.

[18]Source (Statline 2015) http://statline.cbs.nl/Statweb/selection/?VW=T&DM=SLNL&PA=80563ned&D1=20-21&D2=a&D3=11&HDR=T&STB=G1,G2 (2.9 kg C-wood per capita; and 22.5 kg A/B wood/capita, in total 25.4 kg/capita

[19] Verified by multiplying per capita ABC wood generation by the Dutch population.

hazardous. According to the same study in the Netherlands the share is lower, only 6%[20].

In order to estimate the quantities of hazardous post-consumer wood in the other European countries, the share of hazardous wood (7.6% in the Netherlands and 17% in Germany) has been weighted according to the number of inhabitants of both countries, resulting in an **average share of C-wood of 15.4%** in the other EU countries. It is expected that hazardous wood quantities will decrease in the near future as the use of preservatives are banded.

Projection of potentials to 2020 and 2030

The EUwood and EFSOS II studies examined biomass resource potentials under various development scenarios to 2020 and 2030. In the EUwood project data on the amount of PCW for 2010, 2020 and 2030 are given in a graph, see Figure 1. These data have been used in the S2BIOM study as well.

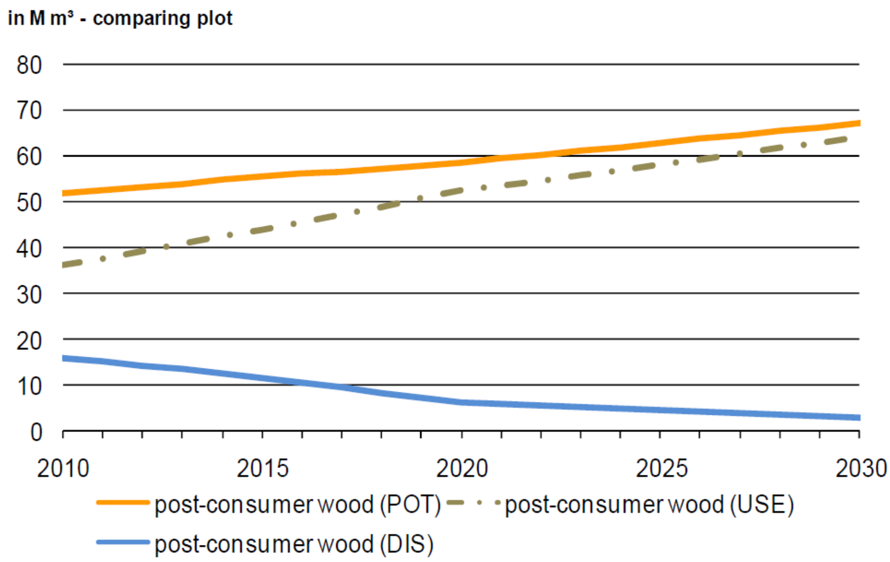


Figure 1: Potential, use and disposal of PCW for the EU 28 countries– scenario A1,

Source: EUwood, Leek: Post-consumer Wood, 2010

[20] Mark van Benthem, Nico Leek, Udo Mantau, Holger Weima; Markets for recovered wood in Europe: Case studies for the Netherlands and Germany based on the Bioxchange project

Conversion factors

The following table summarises conversion factors that have been used to convert mass to volumes and energy. The data is retrieved from the biomass properties database developed in WP2 of S2BIOM.

	NVC_{ar} MJ/kg	Moisture content ($w\%_{ar}$)	Basic density kg/m^3
5.2.1.1 Hazardous post-consumer wood	14.2	13.9%	500
5.2.1.2 Non-hazardous post-consumer wood	16	13.1	500

2.9.3 Methods to estimate costs

2.9.3.1 Cost supply methodology biowaste

This study follows the activity-based costing approach. In principle, the costs of harvesting collection and forwarding to the roadside need to be considered. The cost to put the biowaste in a container at roadside is assumed to be zero. The cost of further collection and processing is covered by the households and organisations that need to discard the biowaste, regardless its possible further application for energy production. Waste collection and treatment is part of the public tasks and the cost for it cannot be allocated to the processor of the waste. In case of biowaste we could define the municipal collection point as “at roadside”. From this municipal collection point, the municipality can select which waste treatment option is preferred, within the framework of European and national policy, considering costs and sustainability of the treatment methods. In short, in this study the biowaste costs at roadside (at the waste treatment plant) are assumed zero.

2.9.3.2 Cost supply methodology post-consumer wood

The cost calculation approach is the activity-based costing approach. In principle, the costs of harvesting collection and forwarding to the roadside needs to be considered. The cost of discarding post-consumer wood in a container at roadside is regarded zero. For instance, demolition activities are performed to make space for another building, and not with the purpose to generate wood waste. Demolition activities will follow legal instruction, i.e. put waste wood fractions in separate containers if this is required by law. For other sources of post-consumer wood such as packaging materials or household waste a similar approach can be applied. Packaging waste is of no value to organisations. Consumers bring wooden furniture to a central collection point, or put it at roadside for pick-up, not the sake of providing energy wood. Once collected and sorted, waste wood fractions have an economic value, which can be considerable if there is sufficient demand. However, as said, this study follows an activity based costing approach, considering the costs, not the economic value of the material. In short, the roadside cost of demolition wood is assumed zero.

3 Determination of imports

3.1 Introduction

Trade of lignocellulosic biomass is increasing on the global scale as the production as well as demand of these commodities is increasing. In terms of the energetic use of wood, wood pellets and wood chips are the most important wood commodities that are imported to the EU. Wood pellets is currently the most commonly globally traded wood energy commodity but trade of both wood pellets and wood chips occur actively between the EU and global regions.

For the S2BIOM project, the potential of import of lignocellulosic biomass was assessed and specified in the form of cost supply curves from countries outside EUROPE such as the Russian Federation, Ukraine, Canada, Brazil and USA. One set of cost supply curves was created to define how much biomass can be imported to EUROPE from the rest of the world for bioenergy purposes (mainly heat and electricity), and one curve defining the potential import of biofuels. Though the two cost supply curves differ in terms of the end use of biomass that is imported, they are both defined in terms of the amount of biomass that could in the future be imported for a specific cost. In the case of bioenergy, the cost supply curve was defined in terms of cubic meters of wood chips and wood pellets that can be imported for heat and electricity production. In the case of biofuels, the cost supply curve was defined in terms of PJ of ethanol (1^{st} and 2^{nd} generation) and biodiesel that can be imported for the transport sector.

The assessment of trade potential mainly focused on a subsection of the resources from forestry and agriculture land. This as reliable data is difficult to get on a global scale for all resource categories and as a number of the categories is not being traded due to their inherent characteristics complicated their trade and use for industrial purposes. The lignocellulosic biomass categories that were considered for the two cost supply curves are:

Bioenergy:

- Short rotation coppice on agricultural land
- Stemwood from thinning and final fellings
- Stem and crown biomass from early thinnings
- Logging residues from thinnings and final fellings
- Industrial by-products (sawdust, wood chips, bark etc.)

Biofuels:

- Ethanol from woody biomass

- Ethanol from wheat, corn and sugar cane
- Biodiesel from rape, sunflower, soya and palm oil

3.2 Description of selected approach

3.2.1 Overview of approach

In the following section, we will broadly describe how the assessment of the import supply potential has been done. The trade related cost supply curves for lignocellulosic biomass has been estimated utilizing a full economic equilibrium model known as GLOBIOM (Global Biosphere Management Model) (Havlík et al. 2014) which gives a detailed biophysical representation of the agricultural, forestry, and bioenergy sectors. GLOBIOM is a partial equilibrium model designed to assess the resource efficiency of biomass use, including energy production, livestock management, and food and timber production. In essence, it is an economic model that jointly covers the forest, agricultural, livestock, and bioenergy sectors, inherently allowing it to consider a range of direct and indirect implications of biomass use. GLOBIOM has a detailed biophysical basis (EPIC and G4M), which ensures that the processes of biomass production, input needs, by-products, environmental impacts and efficiencies are well captured. Estimates of harvesting potentials and harvesting costs are sourced from the forestry model G4M (Gusti, Havlik et al. 2008; Kindermann, Schörghuber et al. 2013), for each spatial unit containing forest, assuming current management practices.

Within the GLOBIOM modelling approach, land use change is endogenously addressed within the modelling framework by the selection of one type of use for each location. Availability and cost depend on the land use change dynamics and the competition of resources. The GLOBIOM model projects the land available for various land categories and determine, on the basis of macro-economic assumptions (GDP, population, diet patterns, etc.) in accordance to the SSP2 "Middle of the Road" scenario, the utilization of land. On this base, increasing trade of lignocellulosic biomass was evaluated based on the following procedure. For creating the cost supply curve the model was run with an added demand of biomass represented by a price (USD per ton of dry mass or USD per PJ) reflecting an arbitrary price that large scale energy producers may be willing to pay for the feedstocks (in the case of bioenergy) or final commodity (in the case of biofuels). For 2020 and 2030, model result indicates the additional amount of biomass that can be supplied to a region by trade. By running the model for a range of biomass prices, the trade related cost supply curves was created.

As GLOBIOM is an economic model, these trade related cost supply curves will reflect the possibility in competition with the use of resources for other purposes, which is in contrast to a "food/feed first" perspective that is also commonly utilized in these types of studies. Note that some of the origins as describes above are not modelled as single regions within the GLOBIOM models. As such, the cost supply curve cannot be created sole for that country or region as it cannot be singled within the model. Due to this, the cost supply curves will be approximate and not represent the interlinkage with countries within the same modelling region.

3.2.2 Overview of trade representation in GLOBIOM

In7ternational trade of the considered feedstocks, processed, and final commodities from the forest, agriculture, and livestock sectors are computed endogenously within the GLOBIOM model between geographical regions. Trade of commodities is as such modelled following the spatial equilibrium approach so that bilateral trade flows between individual regions can be traced for each commodity. This approach applies both to feedstocks commodities (crops, residues, co-products) from the forest, agricultural, and livestock sector, as well as to semi-finished and final end-use products (wood, conventional and advanced biofuels). Trade is furthermore based purely on cost competitiveness as goods are assumed to be homogenous. This implies that imported goods and domestic goods are assumed to be identical and the only differences in their prices are due to the trading costs. There are two components in international trading costs in the model: international transportation costs which are mainly computed based on distance, and tariffs (Figure 23).

Within the model, 2000 year bilateral trade flows are first taken from BACI database which is an initiative of the CEPII (Fontagné et al., 2008) to provide reconciled values and quantities of COMTRADE annual trade statistics at the HS6 product level. BACI provides the historically trade flows where the trade between countries is fully reconciled such that reported imports for country A from country B, fully match that of reported export from country B to country A. A trade calibration method (Jansson and Heckelei, 2009) is applied to reconcile bilateral trade flows with net trade as computed as the difference between the production in a region minus all domestic uses reported by the FAO. In addition, the trade calibration approach ensures that when two regions trade together, their prices only differ by the trading costs for the base year of 2000. After 2000, the model is freely allowed to elaborate on future trade flows. For this, non-linear trade costs are assumed when trade increase with the amount of traded quantities.

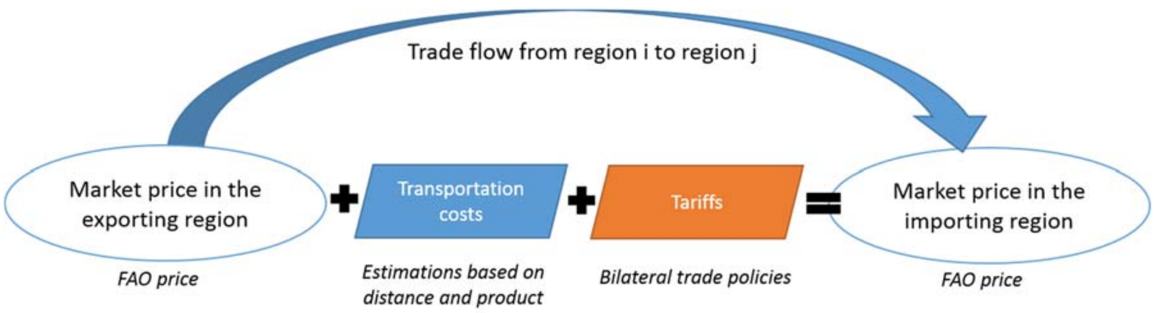


Figure 23 Price determination in the context of international trade in GLOBIOM.

3.2.3 Estimated cost supply curves

The final cost supply curves were estimated for 2010, 2020, and 2030. In term of the cost supply curve for bioenergy, the import potential is shown in Figure 23, where the potential is shows in aggregate terms covering both import of wood chips and wood pellets. As shown in Figure 24, the import potential to EU from the rest of the world of wood chips and wood pellets is substantial.

In terms of wood chips, the import to EU is currently increasing following a global trend of increasing trade of wood chips. Two major import routes of woodchips to the EU can currently be identified. Hardwood chips are imported with sea vessels to Spain and Portugal mainly from Uruguay, Brazil, Canada, Congo and Liberia. According to RISI the total Atlantic imports of woodchips to Spain and Portugal was about 2 million m^3. Another trade flow of wood chips originates mainly from Russia to Finland. About 2.2 million m^3 (2012) of chips was imported by Finland from Russia. It is important to note that these historically reported volumes do not separate the chips for pulp or wood based panel production and energy production. It is estimated by a study from the IEA Bioenergy that less than 10% of the annually reported global wood chip trade volumes are energy-related. In terms of the potential to increase the trade of wood chips for energy purposes, the main increase is estimated in terms of trade from Russia and North Africa due high trading costs. Relatively low energy density, high moisture content and variable particle size and shape of wood chips are the main factor to limited geography of wood chips trade to energy purposes.

The potential to increase import of wood pellets is on the other more substantial than that of wood chips. Wood pellets are, by far, currently the most important solid wood fuel traded internationally. Demand in the EU draws currently the largest trade flows of wood pellets from North-America and Russia. Import of wood pellets to the EU from outside was about 3.2 million tonnes in 2012 and customs statistics show that the imports to the EU in 2013 increased to 5.7 million tonnes. The US and Canada export about 2.7 and 2.0 million tonnes of pellets to the EU respectively, Russia about 0.7 million tonnes/a. Most of the exports from North-America are going to UK, Netherlands, Belgium and Denmark. Russian exports are targeted to Sweden and Denmark.

The potential to increase in import of wood pellets to the EU is estimated to be mainly related to be three major exporting countries: USA, Canada, and Russia. The US and Canada have been the most important sources of industrial wood pellets over the last decade. The imports from North America have been increasing during the last years and so far peak volumes 2.8 million tonnes from The US and 1.9 million tonnes from Canada were recorded in 2013. North American exports are directed to the UK, Benelux, Denmark and a small part to Italy. Russia has also increased its significance in the EU industrial wood pellet export markets. During 2009-2013 Russian exports to the EU have almost doubled from 0.4 million tonnes to 0.7 million tonnes. Major countries importing Russian industrial wood pellets are Sweden and Denmark where pellets are combusted in coastal CHP plants. Due to volatile nature of wood pellet production in Russian mills, the export markets are not as stable or established as on the Atlantic side of the EU.

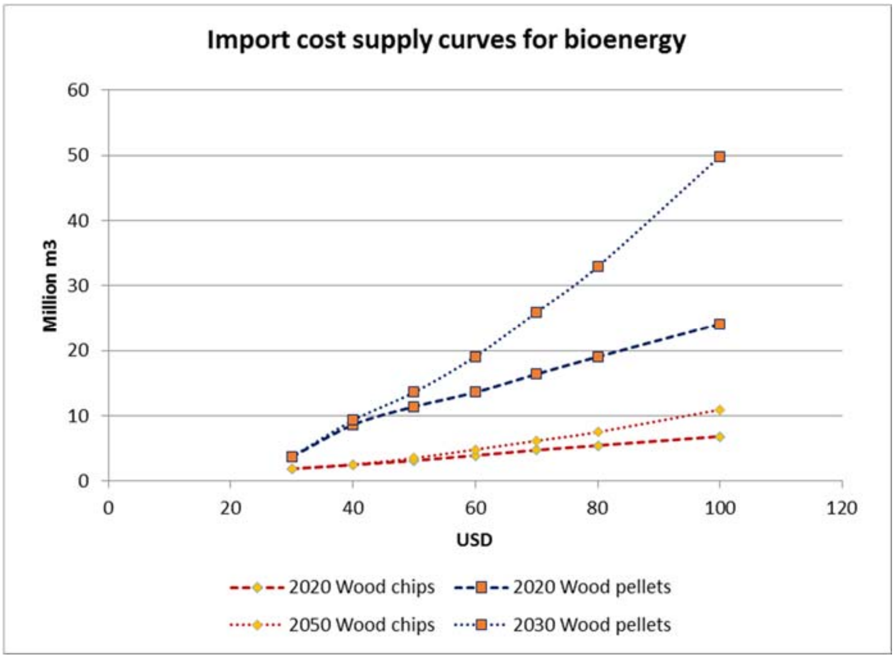


Figure 24 The estimated cost supply curves in 2020 and 2030 for bioenergy. The potential is defined in terms of import of wood chips and wood pellets [Million cubic meters], while the price is defined in terms of the cost that a consumer needs to pay for the feedstock [USD per cubic meter]

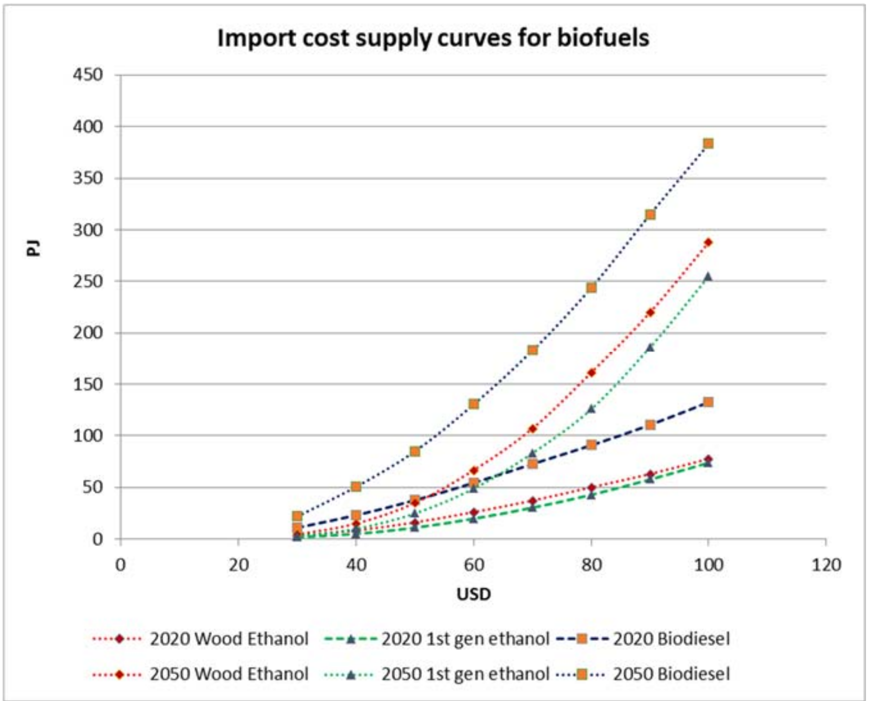


Figure 25 The estimated cost supply curve in 2020 and 2030 for biofuels. The potential is defined in terms of import of 1st generation ethanol from wheat, corn and sugar cane, 2nd generation ethanol from woody biomass, and biodiesel from rape, sunflower, soya and palm oil [PJ], while the price is defined in terms of the cost that a consumer needs to pay for the commodity [USD per PJ]

3.3 Approach specification

List of data sources	A large amount of publically available and processes data is being used in the models defined above. These kind of information ranges from FAO statistics on food production, GLC global land cover data, FAO FRA statistics on afforestation/deforestation, FAO stat on production of woody commodities, SSP2 statistics of the development of social-economic drivers and so forth.
List of models & tools	GLOBIOM, G4M, EPIC
List of constraints	The models that will be used are functional but rely on a significant amount of data. For creating estimates that are plausible, information concerning the current state will be highly valuable. Specifically important for this task will be information concerning current trade flows.
List of reductions for alternative use	None to consider at this instant.
Aspects that can be made subject to scenario differentiation	Scenarios can potentially be created and utilized in the form of trade costs between regions. However, it is currently envisioned that import estimates will not be subject to sustainability constraints or grading (baseline / high) as considered and delivered with the project.
Brief description of the methodology for the assessment of the current use, currently unused potential & of the future potentials	The interlinked GLOBIOM and G4M models will here be used to create cost supply curves of biomass trade (import). This will be assessed for each region by introducing a price for which consumers are willing to pay for the biomass. From this the model will estimate the increase in trade and as such the availability. By running the model for a number of price scenarios, the cost supply curves will be formed.
Spatial scale and spatial disaggregation	Data is clusters of 5 arc-minute pixels belonging to the same country, altitude, slope, and soil class, and to the same 30 arc-minute pixel. Production is adjusted to meet the demand at the 30 regional scale. Cost supply curves for import will as such be created on the regional scale and endogenously incorporating information on the 5 arc-minute pixels level.
Source project (if part of the data collection and processing was done outside S2BIOM including brief description of the status of the data)	Most of the data that will be used and processed within the GLOBIOM and G4M models has been collected, unified, and controlled in other projects. Some data concerning trade of woody biomass commodities will within this project be collected and also incorporated into the model for the scenario creation.
Reference literature	Gusti, M., P. Havlik, et al. (2008). "Technical description of the IIASA model cluster." International Institute for Applied System Analysis

	(IIASA). Havlík, P., U. A. Schneider, et al. (2011). "Global land-use implications of first and second generation biofuel targets." Energy Policy 39(10): 5690-5702. Havlík P, et al. Climate change mitigation through livestock system transitions. Proceedings of the National Academy of Sciences (2014) 111:3709-3714. Kindermann, G. E., S. Schörghuber, et al. (2013). "Potential stocks and increments of woody biomass in the European Union under different management and climate scenarios." Carbon Balance and management 8(1): 2 %@ 1750-0680.
List of detailed level categories	The cost supply curves that are envisioned will consider trade of biomass originating from the following categories of sources • Bioenergy: o Short rotation coppice on agricultural land o Stemwood from thinning and final fellings o Stem and crown biomass from early thinnings o Logging residues from thinnings and final fellings o Industrial by-products (sawdust, wood chips, bark etc.) • Biofuels: o Ethanol from woody biomass o Ethanol from wheat, corn and sugar cane o Biodiesel from rape, sunflower, soya and palm oil
Units	The final cost supply curve will be defined in terms of USD per cubic meter of woody biomass and USD per PJ of biofuel

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Appendix 1 Crop yield simulation model for biomass crops

Table 56 Key crop characteristics

Factors	Miscanthus	Switchgrass	Giant Reed	Reed canary grass	Cardoon	Willow	Poplar	Eucalyptus
Latin name	*Miscanthus spp.*	*Panicum virgatum L.*	*Arundo donax L.*	*Phalaris arundinacea L.*	*Cynara cardunculus L.*	*Salix spp.*	*Populus spp.*	*Eucalyptus spp.*
Photosynthetic system	C4	C4	C3	C3	C3	C3	C3	C3
adaptation range in EU	Cold and warm regions of EU	Cold and warm regions of EU	Warm region of southern EU	Cold and wet regions of EU	Mediterranean region	North EU	Central and south EU	South EU
Rotation time/age of plantation (year)	15 to 20	15	15 to 20	10 to 15	10 to 15	12 to 25	12 to 30	12 to 25
Propagation	rhizomes, microprop. plants	seed	rhizomes, microprop. plants	seed	seed	cuttings	cuttings	Cuttings
Harvest period	Annually fall or spring	Annually fall or spring	Annually fall or spring	Autumn / early spring	Late summer	harvested on 3–4 years rotation Winter	harvested on 3–7 years rotation Winter	harvested on every 3-7 years rotation Winter
Growing minimum (°C)	10	10	5	7	5	0	0	5
Growing maximum (°C)	40	35	35	30	35	30	30	35
Water requirement (mm)	High	Medium	Low	High	Low	High	Medium	Medium
Fertilizer input (N) (kg ha/N/year)	0 - 100	0 - 70	50 - 100	50 - 140	50 - 100	80 - 150	110 - 450	60 - 125
Dry biomass (Mg ha^{-1} d.m.)	5 to 30	5 to 25	8 to 37	3 to 15	5 to 23	10 to 30	7 to 28	10 to 26
Tolerance to dry conditions	High	High	High	Medium	High	Low	Medium	Medium

Table 57 Parameters and factors used in crop yield estimation to dedicated cropping

Crop	minimun water requirement	Length season	min. start day	Accumulative growing season (fraction)				min. temp (basetemp)	Growing degree days	crop coefficient stage (Kc)				Photosyntetic system	WUE	HI
	mm	day	day	f. initial	f. develop.	f. mid season	f. late season	C°	C°	f. initial	f. develop.	f. mid season	f. late season		g/l	%
miscanthus	500	210	80	0.21	0.34	0.84	1	9	2000	0.48	1.05	1.41	0.95	C4	3.3	0.7
switch grass	450	210	80	0.18	0.31	0.80	1	9	2220	0.50	0.99	1.30	0.80	C4	3	0.6
giant reed	400	220	90	0.21	0.32	0.78	1	10	2400	0.54	1.01	1.74	1.10	C3	3.1	0.7
rcg	650	190	80	0.20	0.30	0.80	1	7	1800	0.50	1.00	1.40	1.00	C3	2.2	0.6
cardoon	350	250	90	0.10	0.20	0.80	1	10	2425	0.50	0.70	1.00	0.95	C3	3.13	0.6
willow	620	300	80	0.16	0.39	0.84	1	5	2200	0.40	1.00	1.50	0.50	C3	3	0.65
poplar	600	300	80	0.16	0.39	0.84	1	7,5	2200	0.40	1.00	1.50	0.40	C3	2.9	0.6
eucalyptus	500	300	90	0.16	0.39	0.84	1	10	2200	0.40	1.00	1.50	0.40	C3	2.7	0.65

Source: Zegada et al 2013; Mantineo et al. 2009; Cosentino et al. 2007; Triana F. et al 2014; Mueller et al. 2005; Katerji et al. 2008; Fernandez J. 2009; Monti et Zegada-Lizarazu. 2012; Christou et al 2003; Hickman et al. 2010; Nassi o di nasso et a.l 2011; Garofalo et al. 2013; Curt et al. 1995; Erickson et al. 2012; Sugiura A. 2009; Guidi et al. 2008; Angelini et al. 2009; Stričević et al. 2015; Lasorella 2014; Curt et al. 1998; Price et al. 2004; Alexopoulou et al. 2015; El Bassam 2010

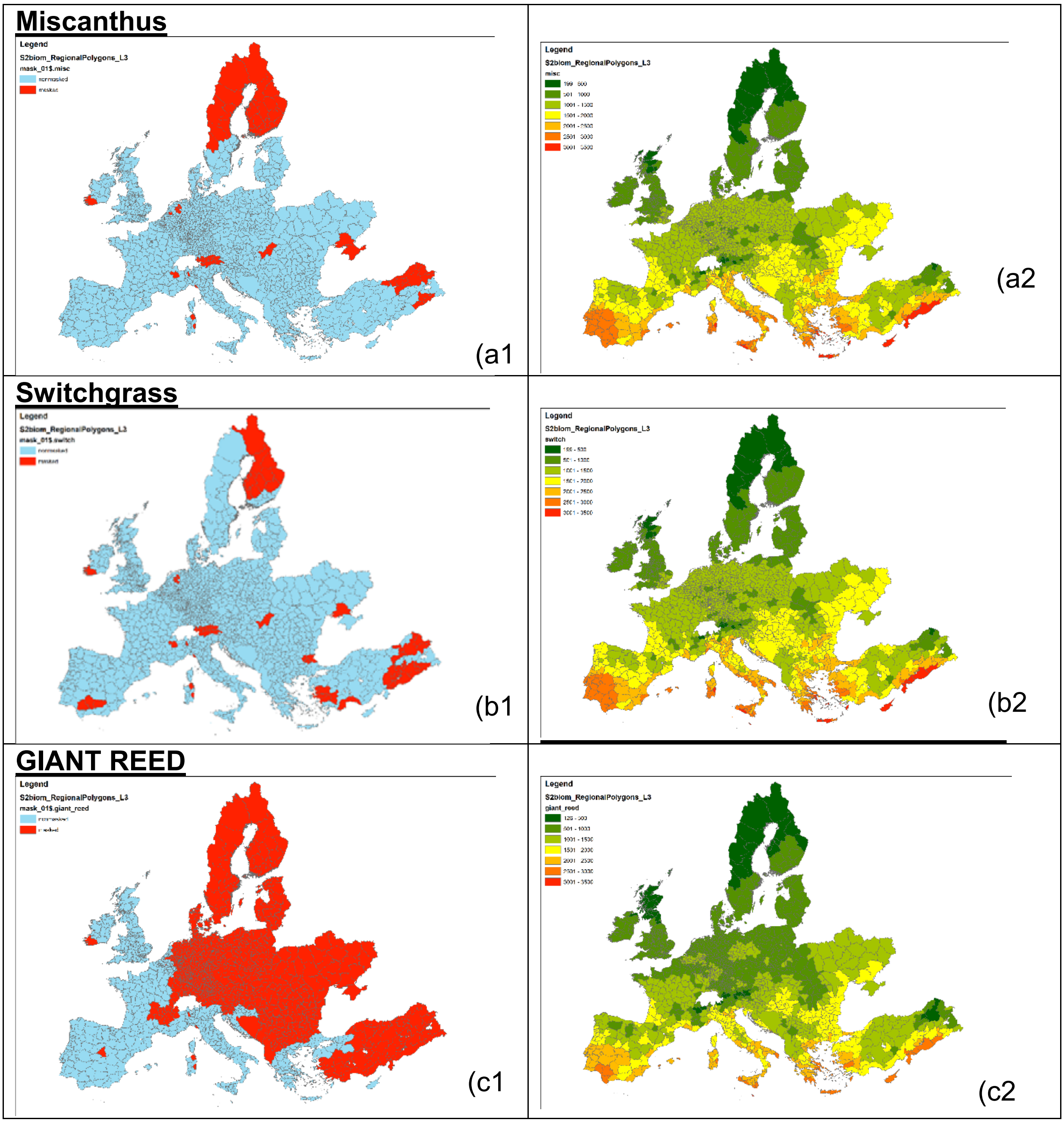
Table 58 Description of the scientific references collected on Nuts3 level to Miscanthus

Country/ Zone	*Location*	*NUTS3 code*	*Crop age (year)*	*Yield (Mg ha^{-1} d.m.)*	*Crop management*	*References*
United Kingdom	Hampshire - ADAS Bridgets	UKJ36	7	16.8		Price et al. 2004
United Kingdom	Aberystwyth	UKL14	7	14.5		Zatta et al. 2014
United Kingdom	Rothamsted	UKH23	14	12.8	Fert. 0-120 kg N. (not influence yield)/ winter harvest	Christian et al. 2008
Ireland southern	Cashel	IE024	15	13.4	Harvest autumn	Clifton-Brown et al. 2007
Ireland southern	Cashel	IE024	15	9	Harvest spring	Clifton-Brown et al. 2007
Denmark	Foulum	DK041	18	13.1	Harvest late autumn	Larsen et al. 2014
Germany	Ihinger hof (Iho)	DE244	3	29 to 30	First year Irrig. 300mm and fert. 50 kg N.	Lewandowski and Heinz. 2003
Germany	Durmersheim	DE124	3	12 to 15	First year Irrig. 300mm and fert. 50 kg N.	Lewandowski and Heinz. 2003
Germany	Klein Markow	DE80K	4 to 9	7.5 to 12.6	N fertilizer/ plot size 45 m^2	Kahle et al. 2001
Germany	Boitzenhagen	DE914	5 to 7	8.8 to 13.5	N fertilizer/ plot size 300 m^2	Kahle et al. 2001
Germany	Guntersleben	DE26C	6 to 8	16.4 to 19.8	N fertilizer/ plot size 87 m^2	Kahle et al. 2001
Serbia	Zemun	RS111	6	16.5	Irrig. only stablishment (40 mm)/ fert.	Stricevic et al. 2015
Serbia	Zemun	RS111	6	21 to 23	Irrig. only stablishment (40 mm)/fert. 50-100 kg N.	Stricevic et al. 2015
France	Grignon	FR103	21	14.2	Irrig. and Fert. In the first year of the establishment	Dufosse et al. 2014
France	Estrées-Mons	FR223	5	13.94	Fert. rate did not effect	Lasorella et al. 2011
Italy	Pisa	ITI17	12	28.7	No Irrigation	Angelini et al. 2009
Italy	Catania	ITG17	22	13.3	Irrig. 1st-3rd year (80mm, 215.5mm, 76.5mm respectly)	Alexopoulou et al. 2015
Italy	Enna	ITG16	5	11 to 27	Irrig. 115-150mm (1st-3rd year, 25%)	Mantineo et al. 2009
Italy	Enna	ITG16	5	18 to 30	Irrig. 438-450mm (1st-3rd year, 75%)	Mantineo et al. 2009
Italy	Catania	ITG17	3	14 to 17	Irrig. 15.8 mm (25%) irrigation/ fert. 0 kg N.	Cosentino et al. 2007
Italy	Bologna	ITH55	11	19.64	Irrig. During establishment year/Fert. rate did not effect/ plot size 90 m^2	Lasorella et al. 2011
Italy	Trisaia	ITF52	13	12.7	Irrig. During establishment year/Fert. rate did not effect/ plot size 50 m^2	Lasorella et al. 2011
Greece	Thessaly	EL613	5	28 to 28	Irrig. 400-600 mm (4-5 cycle)	Danalatos et al. 2007
Greece	Aliartos	EL641	6	14.41	Irrig. During establishment year/Fert. rate did not effect/ plot size 50 m^2	Lasorella et al. 2011

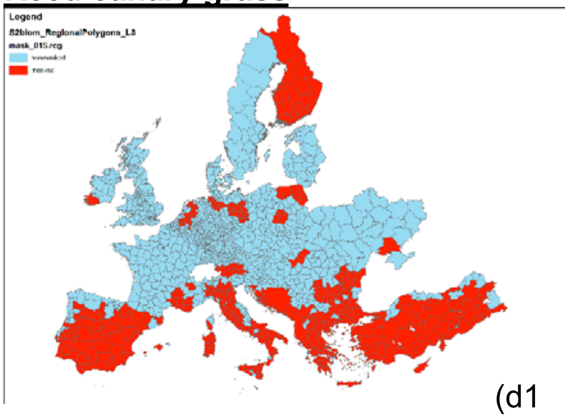
Appendix 2 Crop suitability maps

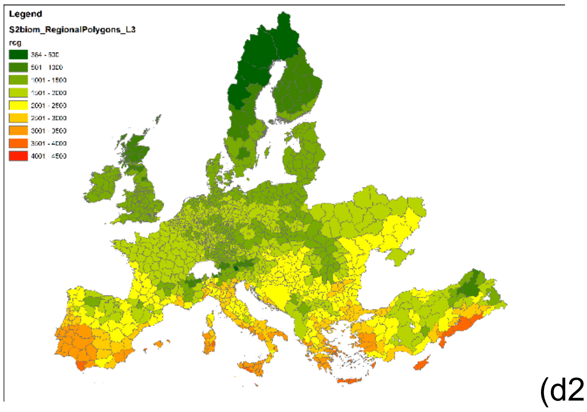
Figure 26 Crop suitability maps

a1 (left): Suitability masks per crop (red=not suitables/blue=suitable)/ **a2 (right)**: Growing degree days from yield model (days)

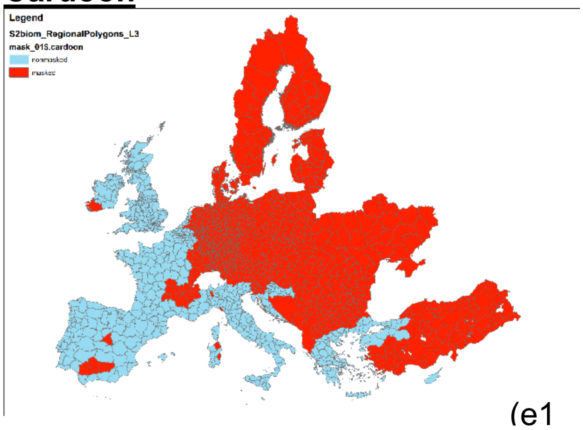


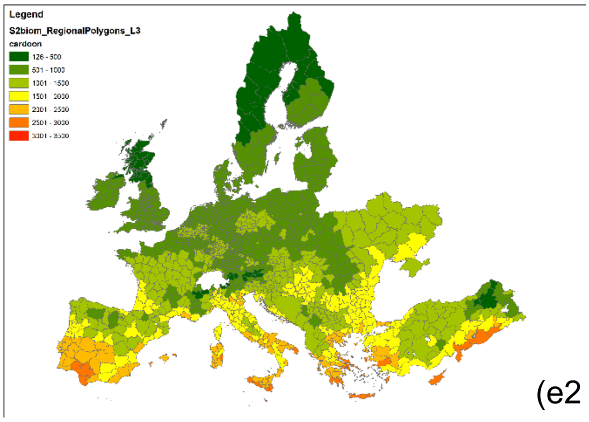
Reed canary grass



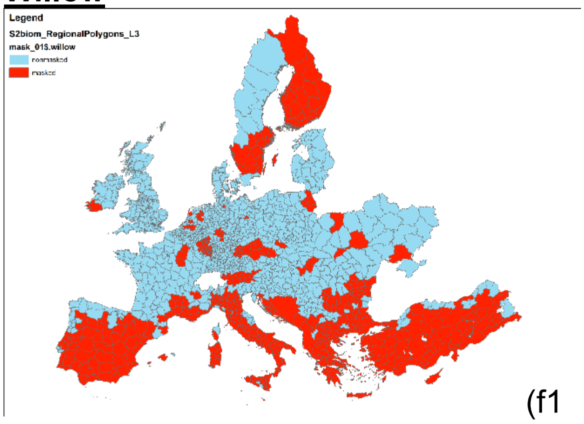


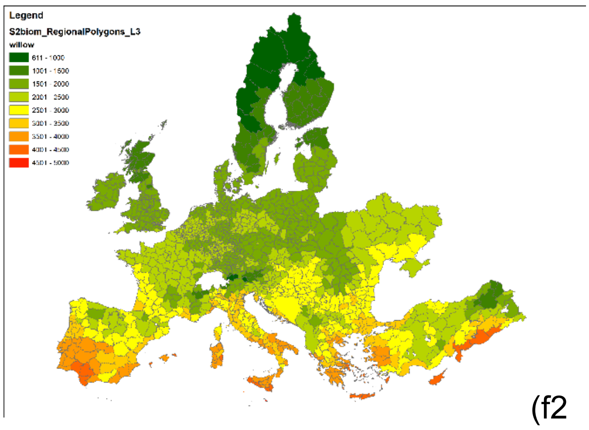
Cardoon



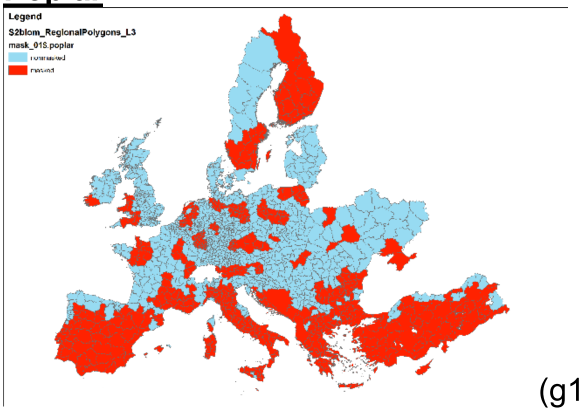


Willow

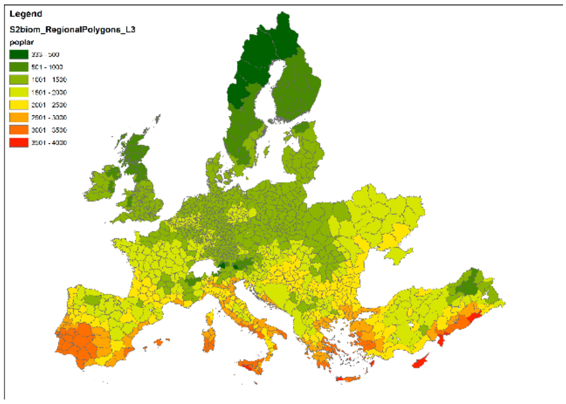




Poplar

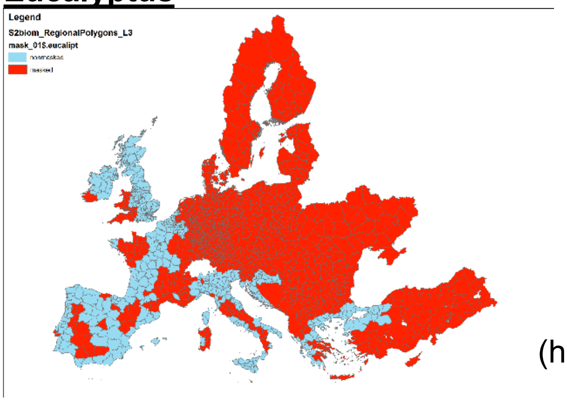


(g1

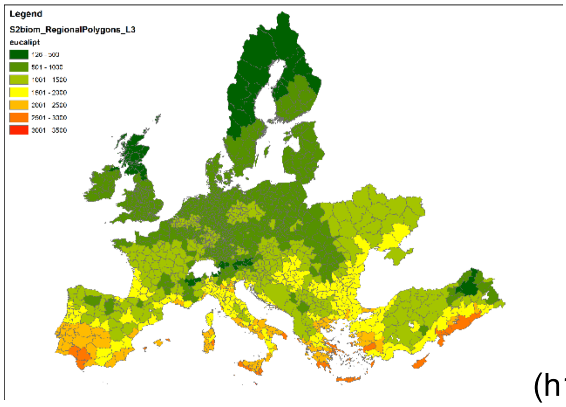


(g2

Eucalyptus



(h1



(h1

Appendix 2 Constraint definitions of forestry potentials

Table 59 to Table 62 provide a detailed overview of the assumptions made to quantify the constraints according to the estimated woody biomass potentials for different types of woody biomass and felling activities.

Table 59 Maximum extraction rates for extracting logging residues from final fellings due to environmental and technical constraints.

Type of constraint	Technical Potential	High Potential	Base Potential
Site productivity	Not a constraining factor	Not a constraining factor	35% extraction rate on poor soils (Acrisol, Podzoluvisol, Histosol, Podzol, Arenosol, Planosol, Xerosol); not a constraining factor on other soils
Soil and water protection: ruggedness	Not a constraining factor	70% on slopes up to TRI highly rugged; 0% over TRI highly rugged,	70% on slopes up to TRI moderately rugged; 0% over moderately rugged,
Soil and water protection: Soil depth	Not a constraining factor	Not a constraining factor	0% on Rendzina, Lithosol and Ranker (very low soil depth)
Soil and water protection: Soil surface texture	Not a constraining factor	Not a constraining factor	0% on peatlands (Histosols)
Soil and water protection: Soil compaction risk	Not a constraining factor	Not a constraining factor	0% on soils with very high compaction risk; 25% on soils with high compaction risk; not a constraining factor on other soils
Biodiversity: protected forest areas	not a constraining factor	0%; not a constraining factor in areas with high or very high fire risk	0%; not a constraining factor in areas with high or very high fire risk
Recovery rate	70% up to TRI highly rugged; 0% over TRI highly rugged,	70% on slopes up to TRI highly rugged; 0% over TRI highly rugged,	70% on slopes up to TRI moderately rugged; 0% over moderately rugged,
Soil bearing capacity	0% on Histosols, Fluvisols, Gleysols and Andosols ,not a constraint in Finland and Sweden	0% on Histosols, Fluvisols, Gleysols and Andosols ,not a constraint in Finland and Sweden	0% on Histosols, Fluvisols, Gleysols and Andosols

Table 60 Maximum extraction rates for logging residues from thinnings due to environmental and technical constraints.

Type of constraint	Technical Potential	High Potential	Base Potential	User Defined Potentials: Increased biodiversity protection (2 options on top of base potential)	User defined potentials: soil and biodiversity protection: no stump extraction
Site productivity	Not a constraining factor	70%	0% on poor soils (Acrisol, Podzoluvisol, Histosol, Podzol, Arenosol, Planosol, Xerosol); 33% on other soils	0% on poor soils (Acrisol, Podzoluvisol, Histosol, Podzol, Arenosol, Planosol, Xerosol); 33% on other soils	0% on poor soils (Acrisol, Podzoluvisol, Histosol, Podzol, Arenosol, Planosol, Xerosol); 33% on other soils
Soil and water protection: Slope	Not a constraining factor	70% up to TRI highly rugged; 0% over TRI highly rugged,	70% up to TRI moderately rugged; 0% over TRI moderately rugged,	70% up to TRI moderately rugged; 0% over TRI moderately rugged	70% up to TRI moderately rugged; 0% over TRI moderately rugged,
Soil and water protection: Soil depth	Not a constraining factor	0% on Rendzina, Lithosol and Ranker (very low soil depth)	0% on Rendzina, Lithosol and Ranker (very low soil depth)	0% on Rendzina, Lithosol and Ranker (very low soil depth)	0% on Rendzina, Lithosol and Ranker (very low soil depth)
Soil and water protection: Soil surface texture	Not a constraining factor	33% on peatlands (Histosols)	0% on peatlands (Histosols)	0% on peatlands (Histosols)	0% on peatlands (Histosols)
Soil and water protection: Soil compaction risk	Not a constraining factor	0% on soils with very high compaction risk; 50% on soils with high compaction risk; not a constraining factor on other soils	0% on soils with very high compaction risk; 25% on soils with high compaction risk; not a constraining factor on other soils	0% on soils with very high compaction risk; 25% on soils with high compaction risk; not a constraining factor on other soils	0% on soils with very high compaction risk; 25% on soils with high compaction risk; not a constraining factor on other soils
Biodiversity: protected forest areas	Not a constraining factor	0%; not a constraining factor in areas with high or very high fire risk	0%; not a constraining factor in areas with high or very high fire risk	0%; not a constraining factor in areas with high or very high fire risk	0%; not a constraining factor in areas with high or very high fire risk

Type of constraint	Technical Potential	High Potential	Base Potential	User Defined Potentials: Increased biodiversity protection (2 options on top of base potential)	User defined potentials: soil and biodiversity protection: no stump extraction
Recovery rate	70% up to TRI highly rugged; 0% over TRI highly rugged.	70% up to TRI highly rugged; 0% over TRI highly rugged.	70% up to TRI moderately rugged; 0% over TRI moderately rugged.	70% up to TRI moderately rugged; 0% over TRI moderately rugged.	70% up to TRI moderately rugged; 0% over TRI moderately rugged
Soil bearing capacity	0% on Histosols, Fluvisols, Gleysols and Andosols ,not a constraint in Finland and Sweden	0% on Histosols, Fluvisols, Gleysols and Andosols ,not a constraint in Finland and Sweden	0% on Histosols, Fluvisols, Gleysols and Andosols	0% on Histosols, Fluvisols, Gleysols and Andosols	0% on Histosols, Fluvisols, Gleysols and Andosols

Table 61 Maximum extraction rates for extracting stumps from final fellings due to environmental and technical constraints.

Type of constraint	Technical Potential	High Potential	Base Potential	User Defined Potentials: Increased biodiversity protection 2 options on top of base potential	User defined potentials: soil and biodiversity protection no stumps
Countries	**All**	**All**	**Finland, Sweden, UK**	**Finland, Sweden, UK**	**All**
Species	**All**	**All**	**Conifers**	**Conifers**	**Conifers**
Site productivity	Not a constraining factor	70% on poor soils (Acrisol, Podzoluvisol, Histosol, Podzol, Arenosol, Planosol, Xerosol); not a constraining factor on other soils	33% on poor soils (Acrisol, Podzoluvisol, Histosol, Podzol, Arenosol, Planosol, Xerosol); not a constraining factor on other soils	33% on poor soils (Acrisol, Podzoluvisol, Histosol, Podzol, Arenosol, Planosol, Xerosol); not a constraining factor on other soils	0%
Soil and water protection: Slope	Not a constraining factor	0% on TRI highly rugged/extremely rugged; 70% - up to moderately rugged	0% on TRI highly rugged/extremely rugged; 70% - up to moderately rugged	0% on TRI highly rugged/extremely rugged; 70% - up to moderately rugged	0%
Soil and water protection: Soil surface texture	Not a constraining factor	33% on peatlands (Histosols)	0% on peatlands (Histosols)	0% on peatlands (Histosols)	0%
Soil and water protection: Soil depth	Not a constraining factor	0% on soils < 40 cm (including Rendzina, Lithosol and Ranker); 70% on soils >40 cm	0% on soils < 40 cm (including Rendzina, Lithosol and Ranker); 33% on soils >40 cm	0% on soils < 40 cm (including Rendzina, Lithosol and Ranker); 33% on soils >40 cm	0%
Soil and water protection: Soil compaction risk	Not a constraining factor	0% on soils with very high compaction risk; 33% on soils with high compaction risk; not a constraining factor on other soils	0% on soils with very high compaction risk; 15% on soils with high compaction risk; not a constraining factor on other soils	0% on soils with very high compaction risk; 15% on soils with high compaction risk; not a constraining factor on other soils	0%
Biodiversity : protected forest areas	Not a constraining factor	0%	0%	0%	0%
Recovery rate	Not a constraining	Not a constraining	Not a constraining	Not a constraining	0%

Type of constraint	Technical Potential	High Potential	Base Potential	User Defined Potentials: Increased biodiversity protection 2 options on top of base potential	User defined potentials: soil and biodiversity protection no stumps
	factor	factor	factor	factor	
Soil bearing capacity	0% on Histosols, Fluvisols, Gleysols and Andosols; not a constraint in Finland and Sweden	0% on Histosols, Fluvisols, Gleysols and Andosols; not a constraint in Finland and Sweden	0% on Histosols, Fluvisols, Gleysols and Andosols	0% on Histosols, Fluvisols, Gleysols and Andosols	0% on Histosols, Fluvisols, Gleysols and Andosols

Table 62 Maximum extraction rates for extracting stumps from thinnings due to environmental and technical constraints.

Type of constraint	Technical Potential	High Potential	Base Potential	User Defined Potentials: Increased biodiversity protection 2 options on top of base potential	User defined potentials: soil and biodiversity protection: no stump removal
Countries	**All**	**All**	**All**	**All**	**All**
Species	**All**	**All**	**All**	**All**	**All**
Site productivity	Not a constraining factor	70% on poor soils (Acrisol, Podzoluvisol, Histosol, Podzol, Arenosol, Planosol, Xerosol); not a constraining factor on other soils	0%	0%	0%
Soil and water protection: Slope	Not a constraining factor	0% on TRI highly rugged/extremely rugged; 70% - up to moderately rugged	0%	0%	0%
Soil and water protection: Soil surface texture	Not a constraining factor	33% on peatlands (Histosols)	0%	0%	0%
Soil and water protection: Soil depth	Not a constraining factor	0% on soils < 40 cm (including Rendzina, Lithosol and Ranker); 70% on soils >40 cm	0%	0%	0%
Soil and water protection: Soil compaction risk	Not a constraining factor	0% on soils with very high compaction risk; 33% on soils with high compaction risk; not a constraining factor on other soils	0%	0%	0%
Biodiversity: protected forest areas	Not a constraining factor	0%	0%	0%	0%
Recovery rate	0% on TRI highly rugged/extremely rugged; 70% - up to moderately rugged	0% on TRI highly rugged/extremely rugged; 70% - up to moderately rugged	0%	0%	0%
Soil bearing capacity	0% on Histosols, Fluvisols, Gleysols and Andosols; not a constraint in Finland and Sweden	0% on Histosols, Fluvisols, Gleysols and Andosols; not a constraint in Finland and Sweden	0%	0%	0%

Appendix 3 Overview of the Machinery inputs' module in cost model

Table 63 Machine costs, part 1

		General				Capital factors								
Acitivty / treat	Type equipment	Capacity (low, medium, high)	Apt (t)	We (m)	V (km/h)	replace-ment value (€)	techni-cal life (y)	rest value €	depre-ciation rate (%)	interest rate (%)	maintenance &repair & insurance & storage & auxiliary (%)	average annual costs (%)	potential use per annum (hr) or /ha (solar drip irrigation)	machine cost / hr
Traction / power	Tractor 4 wheel (40 - 70 kwH)	L				45000	12	1	0.08	0.02	0.13	0.23	833	12.3
	Tractor 4 wheel (70 - 120 kwH)	M				82000	12	1	0.08	0.02	0.09	0.19	833	19.0
	Tractor 4 wheel (120 - 360 kwH)	H				166000	12	1	0.08	0.02	0.05	0.15	833	30.5
	Fruit tractor (35-45 kwH)	L		1.5		23000	12	1	0.08	0.02	0.10	0.20	800	5.8
	Fruit tractor	M		1.8		35000	12	1	0.08	0.02	0.10	0.20	800	8.9
	Fruit tractor	H		2.2		52000	12	1	0.08	0.02	0.10	0.20	800	13.2
	electric water pump 30 Kw 50 m3/hr	L				6100	15	1	0.07	0.02	0.04	0.13	1000	0.8
	electric water pump 75 Kw 150m3/ hr	M				13500	15	1	0.07	0.02	0.04	0.13	1000	1.7
	diesel water pump 50m3/hr 30m deep	H				22400	15	1	0.07	0.02	0.16	0.24	1000	5.5
cleaning field (removal of roots and shrubs/ remove compaction)	power rake/ mulcher- / flail mower / subsoiler 2m	L		2	5	10000	8	1	0.13	0.02	0.10	0.25	200	12.3
	power rake/ mulcher- / flail mower / subsoiler 3m	M		3	5	15000	8	1	0.13	0.02	0.08	0.23	200	16.9
	power rake/ mulcher- / flail mower / subsoiler 4m	H		4	5	25000	8	1	0.13	0.02	0.06	0.21	200	25.6
ploughing	three furrow reversible	L		1.2	6	8000	14	1	0.07	0.02	0.14	0.23	380	4.9
	six furrow reversible	M		2.4	6	28000	14	1	0.07	0.02	0.14	0.23	380	17.1
	nine furrow reversible	H		3.6	6	49000	14	1	0.07	0.02	0.14	0.23	380	29.8
disking /harrowing/	disk harrow 3m	L		3	6	8500	14	1	0.07	0.02	0.08	0.17	300	4.9
	disk harrow 4m	M		4	8	17500	14	1	0.07	0.02	0.08	0.17	300	10.0

		General				Capital factors								
Acitivty / treat	Type equipment	Capacity (low, medium, high)	Apt (t)	We (m)	V (km/h)	replace-ment value (€)	techni-cal life (y)	rest value €	depre-ciation rate (%)	interest rate (%)	maintenanc e &repair & insurance & storage & auxiliary (%)	average annual costs (%)	potential use per annum (hr) or /ha (solar drip irrigation)	machi ne cost / hr
rotavating	rotavator 5m	H		5	10	25500	10	1	0.10	0.02	0.13	0.25	400	15.9
cultivating / hacking	row crop cultivator 6m	L		6	8	11000	12	1	0.08	0.02	0.06	0.16	200	9.0
	row hoe (rotary) 12m	M		12	10	29500	10	1	0.10	0.02	0.45	0.57	300	56.1
	tined weeder 24 m	H		24	12	49000	12	1	0.08	0.02	0.06	0.16	400	20.0
pressing / rolling	Cambridge- / crosskill roller /cultipacker 3m	L		3	8	3700	14	1	0.07	0.02	0.03	0.12	160	2.7
	Cambridge- / crosskill roller /cultipacker 6m	M		6.25	8	13000	14	1	0.07	0.02	0.03	0.12	160	9.5
	Cambridge- / crosskill roller /cultipacker 10m	H		10.3	8	29500	14	1	0.07	0.02	0.03	0.12	160	21.5
seed drill combinations	3m conventional combination	L		3	10	27500	10	1	0.10	0.02	0.07	0.19	160	32.7
	4.5m vertical tillage system / power harrow	M		4.5	12	75000	10	1	0.10	0.02	0.08	0.20	160	91.4
	6 m vertical tillage system/ power harrow	H		6	14	91000	10	1	0.10	0.02	0.08	0.20	160	113.8
planting	1-row planting machine	L		0.75	4	3700	12	1	0.08	0.02	0.03	0.13	160	3.1
	2-row planting machine	M		1.5	4	6300	12	1	0.08	0.02	0.03	0.13	160	5.3
	4-row planting machine	H		3	6	11000	12	1	0.08	0.02	0.03	0.13	160	9.2
sowing	3m mechanical seeder	L		3	10	12000	12	1	0.08	0.02	0.03	0.13	160	10.0
	3m pneumatic seeder	M		3	10	19000	12	1	0.08	0.02	0.03	0.13	160	15.8
	4,5 m pneumatic seeder	H		4.5	10	28000	12	1	0.08	0.02	0.03	0.13	160	23.3
transport headland - depot	wagon / trailer 2-axes 3 t	L	3	2	15	8000	22	1	0.05	0.02	0.02	0.09	600	1.1
	trailer 2-axes 10 t	M	10	2	15	12500	22	1	0.05	0.02	0.02	0.09	600	1.8
	trailer 3-axes 14 t	H	14	2	15	15000	22	1	0.05	0.02	0.02	0.09	600	2.1
dung /manure application	manure injector 4,5m + vacuumtank 5000 ltr	L	5	4.5	4	24000	10	1	0.10	0.02	0.10	0.22	600	8.8

		General				Capital factors								
Acitivty / treat	Type equipment	Capacity (low, medium, high)	Apt (t)	We (m)	V (km/h)	replace-ment value (€)	techni-cal life (y)	rest value €	depre-ciation rate (%)	interest rate (%)	maintenanc e &repair & insurance & storage & auxiliary (%)	average annual costs (%)	potential use per annum (hr) or /ha (solar drip irrigation)	machi ne cost / hr
	manure injector 6m + tandem vacuumtank 10000 ltr	M	10	6	6	47000	10	1	0.10	0.02	0.15	0.27	600	21.2
	manure injector 9m + tandem vacuumtank 16000 ltr	H	16	9	8	103000	10	1	0.10	0.02	0.11	0.23	600	39.5
artificial fertilizer application	disk / pendulum spreader 1000 ltr	L	1	15	10	5200	10	1	0.10	0.02	0.01	0.13	600	1.1
	disk spreader 3000 ltr	M	3	30	12	14000	10	1	0.10	0.02	0.01	0.13	600	3.0
	disk spreader 8000 ltr	H	8	50	12	48000	10	1	0.10	0.02	0.01	0.13	600	10.4
crop protection spraying	sprayer 1000 ltr with 15 m boom	L	1	15	8	21500	10	1	0.10	0.02	0.03	0.15	300	10.4
	sprayer 2500 ltr with 24 m boom	M	2.5	24	10	45000	10	1	0.10	0.02	0.03	0.15	300	21.8
	sprayer 4000 ltr with 39 m boom	H	4	39	12	71000	10	1	0.10	0.02	0.03	0.15	300	34.3
irrigation installation	hose reel system 48 m3/hr (400m x66 m), 30 kW el. Pump 50m3.hr	L	4	66	4	22200	12	1	0.08	0.0225	0.02	0.13	520	5.4
	hose reel system 69 m3/hr (600m x80 m), 75 kW el. Pump 150m3.hr	M	6	80	4	38100	12	1	0.08	0.02	0.02	0.12	520	9.0
	solar drip irrigation 20 ha, 75 kW el. Pump	H	####	500	1	250000	12	1	0.08	0.022	0.02	0.13	20	1566.7
irrigation automatic operation	hose reel system 48 m3/hr (400m x66 m), 30 kW el. Pump 50m3.hr	L	48	66		22200	12	1	0.08	0.0225	0.02	0.13	520	5.4
	hose reel system 69 m3/hr (600m x80 m), 75 kW el. Pump 150m3.hr	M	69	80		38100	12	1	0.08	0.02	0.02	0.12	520	9.0
	solar drip irrigation 20 ha, 75 kW el. Pump	H	####	500		250000	12	1	0.08	0.022	0.02	0.13	20	1566.7
thinning /	wood harvester light	L		10	0.1	40000	10	1	0.10	0.02	0.15	0.27	500	21.6

		General				Capital factors								
Acitivty / treat	Type equipment	Capacity (low, medium, high)	Apt (t)	We (m)	V (km/h)	replace-ment value (€)	techni-cal life (y)	rest value €	depre-ciation rate (%)	interest rate (%)	maintenanc e &repair & insurance & storage & auxiliary (%)	average annual costs (%)	potential use per annum (hr) or /ha (solar drip irrigation)	machi ne cost / hr
cutting	wood harvester medium capacity	M		15	0.1	120000	10	1	0.10	0.02	0.15	0.27	500	64.8
	wood harvester heavy	H		20	0.1	180000	10	1	0.10	0.02	0.15	0.27	500	97.2
harvesting /tuberous crops	beet or potatoe harvester	L	10	1.5	4	100000	9	1	0.11	0.02	0.10	0.23	300	77.0
	beet or potatoe harvester	M	10	3	5	150000	9	1	0.11	0.02	0.10	0.23	300	115.6
	beet or potatoe harvester self propelled	H	15	3	6	450000	9	1	0.11	0.02	0.10	0.23	300	346.7
harvesting /cutting	maize / willow cutter, 3m	L	0	3	2	58500	8	1	0.13	0.02	0.10	0.25	300	47.8
	maize / willow cutter, 6m	M	0	6	3	115000	8	1	0.13	0.02	0.09	0.24	300	90.1
	maize / willow harvester+ cutter, 9m self propelled	H	0	9	4	513000	8	1	0.13	0.02	0.03	0.18	300	299.3
harvesting/ combining	combine rotor 200 kw; 8500 ltr; 5m	L	10.5	5	4.5	241500	10	1	0.10	0.02	0.03	0.15	300	120.8
	combine rotor 350 kw; 12000 ltr; 9m	M	12	9	6	398000	10	1	0.10	0.02	0.03	0.15	300	199.0
	combine hybrid 400 kw; 12000 ltr; 12m	H	12	12	8	515000	10	1	0.10	0.02	0.02	0.14	300	240.3
harvesting/ mulching prunings	Shredder / mulcher (with big bag)	L	0.19	1.65	2.5	10000	8	1	0.13	0.02	0.08	0.23	350	6.4
	Shredder / mulchers (rear bin)	M	0.5	1.9	4	17000	10	1	0.10	0.02	0.09	0.21	400	8.9
	Shredder / mulchers (front/rear + trailer)	H	2	2.2	5	30000	10	1	0.10	0.02	0.10	0.22	500	13.2
transport combine / cutter /harvester - depot	2 tractor & tipper/ dumpers 8t	L	8	2	12	17000	15	1	0.07	0.02	0.03	0.12	600	6.6
	2 tractor silage wagon 13 t	M	13	2	12	43000	10	1	0.10	0.02	0.04	0.16	600	22.9
	2 tractor silage wagon 21 t	H	21	2	12	80500	22	1	0.05	0.02	0.04	0.11	600	28.3
mowing	Sickle mower / small rotary head 2m	L	0	2	12	6200	10	1	0.10	0.02	0.07	0.19	500	2.4

		General				Capital factors								
Acitivty / treat	Type equipment	Capacity (low, medium, high)	Apt (t)	We (m)	V (km/h)	replace-ment value (€)	techni-cal life (y)	rest value €	depre-ciation rate (%)	interest rate (%)	maintenance &repair & insurance & storage & auxiliary (%)	average annual costs (%)	potential use per annum (hr) or /ha (solar drip irrigation)	machine cost / hr
	rotary mower / disc mower conditioner, rear	M	0	3.1	12	11000	10	1	0.10	0.02	0.07	0.19	500	4.1
	rotary mower front + rear side /disc mower conditioner	H	0	6.4	12	42000	10	1	0.10	0.02	0.04	0.16	500	13.4
turning / raking	wheel / rotary rake 6.5 m	L	0	6.5	12	10000	10	1	0.10	0.02	0.15	0.27	500	5.4
turning / raking	wheel / rotary rake 8 m	M	0	8	12	24000	10	1	0.10	0.02	0.08	0.20	500	9.6
turning / raking	wheel / rotary rake 13 m	H	0	13	12	28500	10	1	0.10	0.02	0.11	0.23	500	13.1
baling	small square baler 0,4x0,5 m / round baler	L	0.3	5	4	34000	8	1	0.13	0.02	0.09	0.24	250	32.0
baling	square baler 0,8x0,7m (1,95m)	M	0.4	9	8	119000	8	1	0.13	0.02	0.09	0.24	250	111.9
	high speed large square baler (2.35m) 1,3mX1,2m	H	0.5	12	12	195000	8	1	0.13	0.02	0.09	0.24	250	183.3
loading / transport / stacking (headland /depot)	two tractor trailer teams	L	32	10	12	35000	22	1	0.05	0.02	0.03	0.09	500	25.3
loading / transport / stacking (headland /depot)	tractor frontloader, stacker, 2 trailers 8t	M	16	18	12	35000	22	1	0.05	0.02	0.03	0.09	500	12.7
loading / transport / stacking (headland /depot)	bale chaser / autostack	H	8	24	12	85000	8	1	0.13	0.02	0.09	0.24	250	79.9

Table 64 Machine costs, part 2

		Auxilary									country indices	
Acitivty / treat	Type equipment	Traction fuel (l/hr)	Traction oil (l/hr)	fuel price (€/l)	oil price (€/l)	Electricty kWh	Electricity price (€/ kWh)	energy & fuel& lubricant cost/hr	cost/ hr incl. traction (excl. fuel)	Source	machine cost /hr	fuel cost/hr
Traction / power	Tractor 4 wheel (40 -70 kwH)	6.3	0.1	1.0	3.1			6.5	12.3	KWIN-agv (2012) /KTBL (online 2015)	18.8	
	Tractor 4 wheel (70 -120 kwH)	9.7	0.1	1.0	3.1			10.0	19.0	KWIN-agv (2012) / KTBL (online 2015)	29.0	
	Tractor 4 wheel (120 - 360 kwH)	16.1	0.2	1.0	3.1			16.6	30.5	KWIN-agv (2012) / KTBL (online 2015)	47.1	
	Fruit tractor (35-45 kwH)	4.0	0.4	1.0	3.1			5.1	5.8		11.0	
	Fruit tractor	5.1	0.4	1.0	3.1			6.3	8.9		15.2	
	Fruit tractor	6.8	0.4	1.0	3.1			8.1	13.2		21.3	
	electric water pump 30 Kw 50 m3/hr					20.0	0.2	3.0	0.8	KTBL (online 2015)		3.8
	electric water pump 75 Kw 150m3/ hr					50.0	0.2	7.6	1.7	KTBL (online 2015)		9.3
	diesel water pump 50m3/hr 30m deep	8.0	0.1	1.0	3.1			16.6	5.5	KTBL (online 2015)		22.1
cleaning field (removal of roots and shrubs/ remove compaction)	power rake/ mulcher- / flail mower / subsoiler 2m								24.6	KTBL (online 2015)	10.5	8.4
	power rake/ mulcher- / flail mower / subsoiler 3m								35.9	KTBL (online 2015)	15.3	12.9
	power rake/ mulcher- / flail mower / subsoiler 4m								56.2	KTBL (online 2015)/ KWIN	24.0	21.4
ploughing	three furrow reversible								17.2	KTBL (online 2015)/ KWIN	7.3	8.4
	six furrow reversible								36.1	KTBL (online 2015)/ KWIN	15.4	12.9
	nine furrow reversible								60.4		25.8	21.4

		Auxilary									country indices	
Acitivty / treat	Type equipment	Traction fuel (l/hr)	Traction oil (l/hr)	fuel price (€/l)	oil price (€/l)	Electricty kWh	Electricity price (€/ kWh)	energy & fuel& lubricant cost/hr	cost/ hr incl. traction (excl. fuel)	Source	machine cost /hr	fuel cost/hr
disking /harrowing/ rotavating	disk harrow 3m								17.2	KTBL (online 2015)	7.3	8.4
	disk harrow 4m								29.0	KTBL (online 2015)	12.4	12.9
	rotavator 5m								46.5	KTBL (online 2015)	19.8	21.4
cultivating / hacking	row crop cultivator 6m								21.3	KTBL (online 2015)	9.1	8.4
	row hoe (rotary) 12m								75.1	KTBL (online 2015)	32.0	12.9
	tined weeder 24 m								50.6	KTBL (online 2015)	21.6	21.4
pressing / rolling	Cambridge- / crosskill roller /cultipacker 3m								15.0	KTBL (online 2015)	6.4	8.4
	Cambridge- / crosskill roller /cultipacker 6m								28.5	KTBL (online 2015)	12.1	12.9
	Cambridge- / crosskill roller /cultipacker 10m								52.0	KTBL (online 2015)	22.2	21.4
seed drill combinations	3m conventional combination								45.0	KTBL (online 2015/ KWIN)	19.2	8.4
	4.5m vertical tillage system / power harrow								110.4	KTBL (online 2015/ KWIN)	47.1	12.9
	6 m vertical tillage system/ power harrow								144.3	KTBL (online 2015/ KWIN)	61.5	21.4
planting	1-row planting machine								15.4	KTBL (online, 2015)	6.6	8.4
	2-row planting machine								24.3	KTBL (online, 2015)	10.4	12.9
	4-row planting machine								39.7	KTBL (online, 2015)	16.9	21.4
sowing	3m mechanical seeder								22.3	KTBL (online 2015/ KWIN)	9.5	8.4
	3m pneumatic seeder								34.9	KTBL (online 2015/ KWIN)	14.9	12.9
	4,5 m pneumatic seeder								53.9	KTBL (online 2015/ KWIN)	23.0	21.4

		Auxilary									country indices	
Acitivty / treat	Type equipment	Traction fuel (l/hr)	Traction oil (l/hr)	fuel price (€/l)	oil price (€/l)	Electricty kWh	Electricity price (€/ kWh)	energy & fuel& lubricant cost/hr	cost/ hr incl. traction (excl. fuel)	Source	machine cost /hr	fuel cost/hr
transport headland - depot	wagon / trailer 2-axes 3 t								13.5	KWIN 2012	5.7	8.4
	trailer 2-axes 10 t								20.8	KWIN 2012	8.9	12.9
	trailer 3-axes 14 t								32.7	KWIN 2012	13.9	21.4
dung /manure application	manure injector 4,5m + vacuumtank 5000 ltr								21.1	KTBL (online, 2015); KWIN	9.0	8.4
	manure injector 6m + tandem vacuumtank 10000 ltr								40.2	KTBL (online, 2015); KWIN	17.1	12.9
	manure injector 9m + tandem vacuumtank 16000 ltr								70.0	KTBL (online, 2015); KWIN	29.9	21.4
artificial fertilizer application	disk / pendulum spreader 1000 ltr								13.5	KTBL (online, 2015)	5.7	8.4
	disk spreader 3000 ltr								22.1	KTBL (online, 2015)	9.4	12.9
	disk spreader 8000 ltr								40.9	KTBL (online, 2015)	17.5	21.4
crop protection spraying	sprayer 1000 ltr with 15 m boom								22.7	KTBL (online, 2015)	9.7	8.4
	sprayer 2500 ltr with 24 m boom								40.8	KTBL (online, 2015)	17.4	12.9
	sprayer 4000 ltr with 39 m boom								64.9	KTBL (online, 2015)	27.7	21.4
irrigation installation	hose reel system 48 m3/hr (400m x66 m), 30 kW el. Pump 50m3.hr								17.7		7.5	8.4
	hose reel system 69 m3/hr (600m x80 m), 75 kW el. Pump 150m3.hr								28.1		12.0	12.9
	solar drip irrigation 20 ha, 75 kW el. Pump								1566.7		668.2	0.0

		Auxilary									country indices	
Acitivty / treat	Type equipment	Traction fuel (l/hr)	Traction oil (l/hr)	fuel price (€/l)	oil price (€/l)	Electricty kWh	Electricity price (€/ kWh)	energy & fuel& lubricant cost/hr	cost/ hr incl. traction (excl. fuel)	Source	machine cost /hr	fuel cost/hr
irrigation automatic operation	hose reel system 48 m3/hr (400m x66 m), 30 kW el. Pump 50m3.hr								6.2		2.6	3.9
	hose reel system 69 m3/hr (600m x80 m), 75 kW el. Pump 150m3.hr								10.7		4.6	9.8
	solar drip irrigation 20 ha, 75 kW el. Pump								0.0		0.0	0.0
thinning / cutting	wood harvester light								33.9	estimate, for better	14.5	8.4
	wood harvester medium capacity	10.0	0.1	1.0	3.1			10.3	64.8	estimate, for better	27.6	13.3
	wood harvester heavy	15.0	0.2	1.0	3.1			15.5	97.2	estimate, for better	41.5	19.9
harvesting /tuberous crops	beet or potatoe harvester								89.4		38.1	8.4
	beet or potatoe harvester								134.6		57.4	12.9
	beet or potatoe harvester self propelled	60.0	0.6	1.0	3.1			61.9	346.7		147.9	79.7
harvesting /cutting	maize / willow cutter, 3m								60.1	KTBL (online, 2015)	25.6	3.9
	maize / willow cutter, 6m								109.1	KTBL (online, 2015)	46.5	9.8
	maize / willow harvester+ cutter, 9m self propelled	46.5	0.6	1.0	3.1			48.2	299.3	KTBL (online, 2015)	127.6	62.1
harvesting/ combining	combine rotor 200 kw; 8500 ltr; 5m	34.9	0.3	1.0	3.1			36.0	120.8	KTBL (online, 2015)	51.5	46.4

		Auxilary									country indices	
Acitivty / treat	Type equipment	Traction fuel (l/hr)	Traction oil (l/hr)	fuel price (€/l)	oil price (€/l)	Electricty kWh	Electricity price (€/ kWh)	energy & fuel& lubricant cost/hr	cost/ hr incl. traction (excl. fuel)	Source	machine cost /hr	fuel cost/hr
	combine rotor 350 kw; 12000 ltr; 9m	61.1	0.6	1.0	3.1			63.0	199.0	KTBL (online, 2015)	84.9	81.2
	combine hybrid 400 kw; 12000 ltr; 12m	69.8	0.7	1.0	3.1			72.0	240.3	KTBL (online, 2015)	102.5	92.8
harvesting/ mulching prunings	Shredder / mulcher (with big bag)								12.3		5.2	6.6
	Shredder / mulchers (rear bin)								17.8		7.6	8.1
	Shredder / mulchers (front/rear + trailer)								26.4		11.3	10.4
transport combine / cutter /harvester - depot	2 tractor & tipper/ dumpers 8t								37.9	KTBL (online, 2015)	16.2	16.7
	2 tractor silage wagon 13 t								83.9	KTBL (online, 2015)	35.8	25.8
	2 tractor silage wagon 21 t								117.7	KTBL (online, 2015)	50.2	42.8
mowing	Sickle mower / small rotary head 2m								14.7	KTBL (online, 2015)	6.3	8.4
	rotary mower / disc mower conditioner, rear								23.1	KTBL (online, 2015)	9.8	12.9
	rotary mower front + rear side /disc mower conditioner								44.0	KTBL (online, 2015)	18.8	21.4
turning / raking	wheel / rotary rake 6.5 m								17.7	KTBL (online, 2015)	7.6	8.4
	wheel / rotary rake 8 m								28.6	KTBL (online, 2015)	12.2	12.9
	wheel / rotary rake 13 m								43.7	KTBL (online, 2015)	18.6	21.4

		Auxilary									country indices	
Acitivty / treat	Type equipment	Traction fuel (l/hr)	Traction oil (l/hr)	fuel price (€/l)	oil price (€/l)	Electricty kWh	Electricity price (€/ kWh)	energy & fuel& lubricant cost/hr	cost/ hr incl. traction (excl. fuel)	Source	machine cost /hr	fuel cost/hr
baling	small square baler 0,4x0,5 m / round baler								44.3	KTBL (online 2015)	18.9	8.4
	square baler 0,8x0,7m (1,95m)								130.9	KTBL (online 2015)	55.8	12.9
	high speed large square baler (2.35m) 1,3mX1,2m								213.8	KTBL (online 2015)	91.2	21.4
loading / transport / stacking (headland /depot)	two tractor trailer teams								126.0	KTBL, KWIN, BioBoost	53.7	16.7
	tractor frontloader, stacker, 2 trailers 8t								44.4		18.9	12.9
	bale chaser / autostack								110.4	Bioboost	47.1	21.4

Appendix 3 Table view of ‘Crop inputs 3’ module

Table 65 Table view of ‘Crop inputs 3’ module.

General info: In this sheet activities are assigned to crop production on the basis of pre-defined patterns (pre-defined sets in rows 5-14; e.g. pattern no 7 means activities take place in year 15,30,45,60; whether there will be an activity in the first year or not is set from colomn AQ onward)

		0= activity not appl	1= pattern 1	2= pattern 2, etc															
patterns over the years			year																
	pattern_nr	activity interval	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
	2	3	0	0	1	0	0	1	0	0	1	0	0	1	0	0	1	0	0
	3	5	0	0	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0
	4	7	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0
	5	10	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
	6	12	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
	7	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
	8	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	9	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	10	1	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
selected cro	**Miscanthus**	**Activity / year**																	
Crop_nr	Crop	cleaning field (removal of roots and shrubs)	ploughing	disking / harrowing / rotavating	cultivating	pressing / rolling	cereal drilling/ power harrowing combi	planting	sowing	transport plant material	dung /manure application	artificital fertilizer application	weed control spraying	irrigation	thinning	harvesting tuberous crop / combining	harvesting /cutting	harvesting /mowing	harvesting/ mulching
	Biomass crops																		
1	Biomass sorghum	0	1	1	1	0	0	0	1	1	0	1	1	0	0	0	1	0	0
2	Miscanthus	8	8	8	0	0	0	8	0	8	0	10	8	0	0	0	0	10	0
3	Switchgrass	7	7	7	0	7	0	0	7	7	0	1	7	0	0	0	0	1	0
4	Giant reed	7	7	7	0	0	0	7	0	7	0	1	7	0	0	0	1	0	0
5	Cardoon	7	7	7	0	0	0	0	7	0	0	1	7	0	0	0	1	0	0
6	Reed Canary Grass	7	7	7	0	7	0	0	7	0	0	1	7	0	0	1	0	0	0
7	SRC Willow	8	8	8	8	8	0	8	0	8	8	2	3	0	0	0	2	0	0
8	SRC Poplar	8	8	8	8	0	0	8	0	8	8	2	3	0	0	0	2	0	0
9	Other SRC	8	8	8	8	0	0	8	0	8	8	2	3	0	0	0	2	0	0