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CLASSIFICATION OF EUROPEAN BIOMASS POTENTIAL FOR BIOENERGY USING TERRESTRIAL & EARTH OBSERVATIONS

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SEVENTH FRAMEWORK PROGRAMME

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List of Abbreviations

Abbreviation	Explanation
FFF	Fibre, food and fodder
BBCH	Biologische **B**undesanstalt, **B**undessortenamt und **CH**emische Industrie (Biological Federal Institute, Federal Office for Plant Varieties and Chemical industry
BEF	Biomass expansion factor
BEE	Biomass Energy Europe (partner project of the same call)
CDM	Clean Development Mechanism
CIS	Core Information Service (part of GEOLAND)
CMS	Core Mapping Service (part of GEOLAND)
CLC	Corine Land Cover
DBFE	Decision Boundary Feature Extraction
DBH	Diameter at breast height
DTM	Digital Terrain Model
DSM	Digital Surface Model
EC	European Commission
EEA	European Environment Agency
EEC	Enhanced Ellipsoid Corrected
EO	Earth Observation (in this context the same meaning as remote sensing)
ERV	Estimated Residue Value (similar to Crop-to-Residue-Ratio)
FAO	Food and Agricultural Organization
FMP	Forest Management Plan
FYROM	Former Yugoslav Republic of Macedonia
GEC	Geocoded Ellipsoid Corrected
GIO	GMES Initial Operations
GIS	Geographical Information System
GMES	Global Monitoring for Environment and Security
HH	Horizontal transmit and receive
HTU	Hydro Thermal Upgrading
HR	High Resolution
HV	Horizontal transmit, Vertical receive
IPCC-GPG	Intergovernmental Panel on Climate Change – Good Practice Guidelines
JRC	Joint Research Center
kNN	K Nearest Neighbor (algorithm)
LCC	Land cover classification
LAI	Leaf Area Index
LEK	Local Expert Knowledge
LiDAR	Light Detection and Ranging
LMA	Local Maximum Algorithm
LoG	Laplacian of Gauss
MMU	Minimum Mapping Unit
NAI	Net Annual Increment
NDVI	Normalized Differenced Vegetation Index
NIR	Near Infrared
NPP	Net Primary Production
NUTS	The Nomenclature of Territorial Units for Statistics or Nomenclature of Units for Territorial Statistics

NFI	National Forest Inventory
PPV	Pixel Production Value
PPRV	Pixel Primary Residue Value
PRG	Perennial Rhizomatous Grasses
PV	Production Value
RADAR	Radio Detection and Ranging
RES	Renewable Energy Sources
RS	Remote Sensing
SAR	Synthetic Aperture Radar
SRC	Short Rotation Coppice
SRTM	Shuttle Radar Topography Mission
TERV	Total Estimated Residue Value
TGS	Total Growing Stock
TPV	Total Production Value
TPRV	Total Primary Residue Value
UAA	Utilised Agricultural Area
UNFCCC	United Nations Framework Convention on Climate Change
VHM	Vegetation Height Model
VHR	Very High Resolution
VV	Vertical transmit and receive

1. Introduction

CEUBIOM[1] is a project funded by the European Commission's 7th Framework Programme submitted in response to an FP7 Call for Proposals to *'develop a common methodology for gathering information on biomass potential using terrestrial and earth observations, and for gathering and disseminating this information'*[European Commission, 2007]. The project deployed a systematic work programme to achieve this objective that started with the assessment of current practices in biomass assessment and resulted in a conceptual framework for harmonisation. Special focus has been given to assessing the conditions in the Western Balkan Countries (WBCs) and to satisfy the needs of the stakeholders from this region.

The need for harmonising biomass assessments has been addressed by the professional community for years pointing out that *'there are no standard measuring and accounting procedures for biomass, so it is often impossible to make comparisons between sets of existing data…'*[Rosillo-Calle et al., 2007]. The urgency for harmonising biomass resource assessment has also been addressed on a political level following the launch of the Biomass Action Plan as the *'first, coordinating step'* that established specific targets and a comprehensive framework for accelerating the deployment of biomass for electricity, heating and transport purposes [European Commission, 2005]. The difficulties in comparing (let alone combining) various datasets have been addressed at several high-level workshops and there was an overall consensus that *'the wide variety of biomass feedstocks make it difficult to put forward a harmonized scheme at this stage'* [European Commission, 2010]. making long-term planning difficult for the sustainable use of Europe's bioenergy resources.

If one considers the various types of approaches, the different methodologies and the broad array of purposes of biomass assessments an almost infinite number of combinations exist as to the ways biomass resources can be assessed. In their report the BEE Consortium[2] compiled a database of about 250 types of assessment out of which they selected 28 for detailed comparison [BEE, 2010]. There is an apparent need for harmonisation and the establishment of a common framework.

On the other hand there is a reason why such a wide range of assessment methods exists and this reason is the complexity of user needs and the corresponding boundary conditions. The purpose of biomass assessments can range from obtaining overall estimates of bioenergy on a global or national level (typically motivated by decision and/or policy making purposes) to serving local user needs (can be very specific for a particular type of biomass/residue taking some unique constraints into account). The methods of doing the actual assessment work would then depend on these purposes taking other constraints (such as available financial resources) into account. The resulting bioenergy studies often produce results that are difficult to compare, because the original purpose of all these assessments is different in most cases. But this fact should be considered as a natural feature of biomass assessments rather than a shortcoming.

Although from a policy-making perspective it would be desirable to create uniform guidelines according to which bioenergy assessments are carried out at all levels, in practice such standard would be unpractical, counterproductive and most likely impossible to create as well. The market players should be able to decide what kind of assessments they require depending on their specific needs and specific boundary conditions. The same stands for academic and

[1] Classification of European Biomass Potential for Bioenergy Using Terrestrial and Earth Observations. Grant Agreement No 213634, www.ceubiom.org
[2] Biomass Energy Europe. Grant Agreement No. 213417, http://www.eu-bee.com

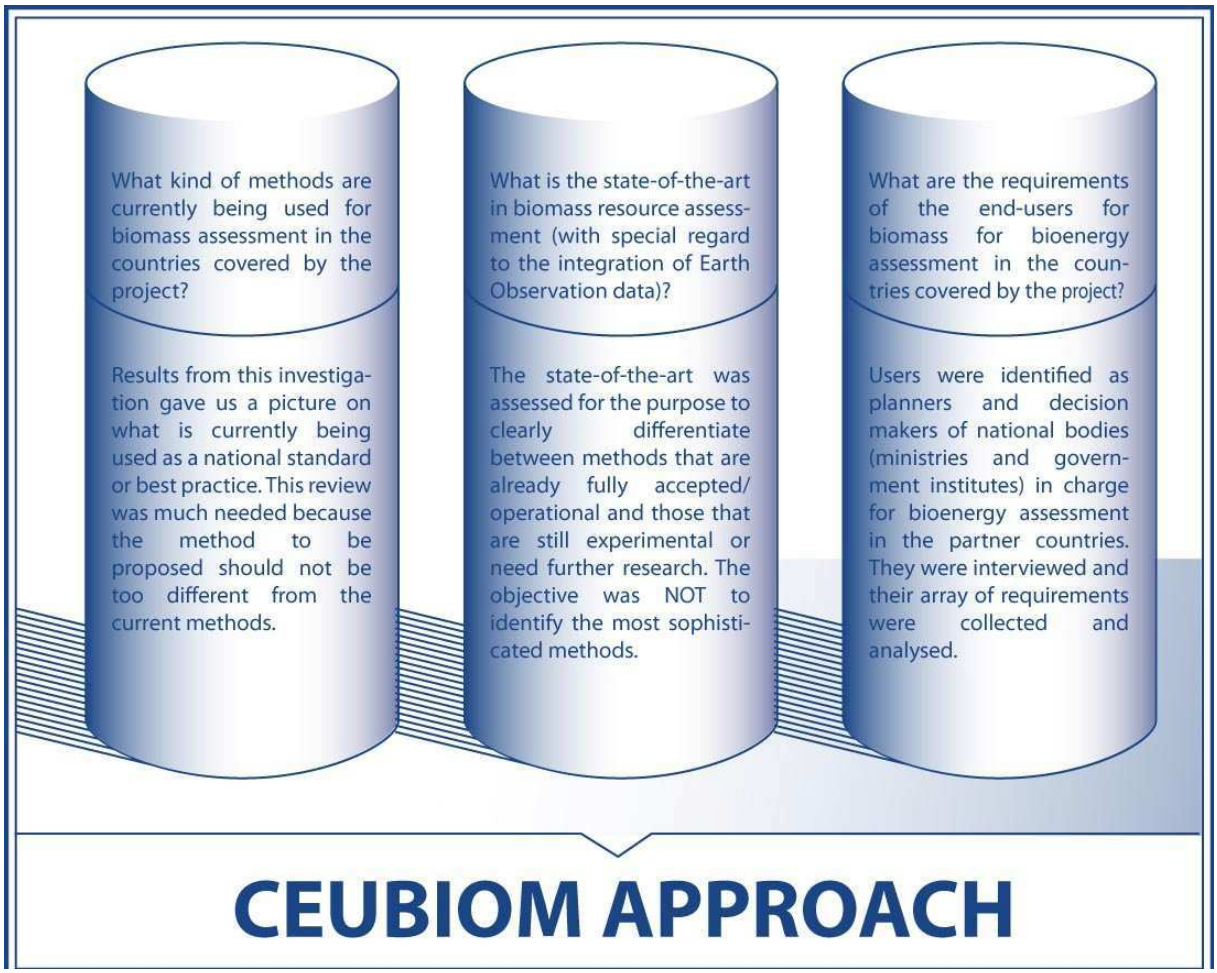
industrial research. There should always be room left for the development of new methods, models and technologies, challenging current practices and exploring new ways of assessing bioenergy. The harmonisation of biomass assessment methods therefore cannot be vertically implemented for all actors of the bioenergy chain.

There is however a sector where the harmonisation in biomass for bioenergy resource assessment is overdue. Biomass resource assessment studies of different scales and scope have been developed by the authorities of EU Member States for decades. These national and regional studies are similar in purpose (provide an overview on the availability of biomass and/or provide updates in the changes bioenergy use or availability). The studies have deployed various internationally accepted approaches and best practices and supported the development of national statistics from the results. But since no uniform criteria have been established on how these policy-support assessments should be carried out the results are difficult to compare and aggregate to European level and for this reason the actual amount and type of bioenergy available for European users is still difficult to establish. There are of course some European-level studies that use existing national and European statistics to provide top-down assessments on a European level [EEA 2006a,b, EEA 2007a,b]. Still, the overall accuracy and reliability of studies that use figures from national statistics (that may have been based on different methods) could be further improved if the methods are harmonized.

The need to provide comparable and compatible datasets on a national level has become imperative in Europe. Member states are now explicitly encouraged by the EC to develop national biomass action plans. A uniform methodology for assessing bioenergy will be needed for a European-level aggregation of data and statistics. This further underlines the need for harmonisation not only of the statistics. Also, the harmonisation of methods for how these national assessments are to be carried out is imperative because the issue of availability and assessment of biomass is *"considered important by almost all members"* [NBAP, 2008].

CEUBIOM intends to contribute to these efforts by focusing exclusively on the public sector (i.e. national governments and municipalities) with the mission to propose a framework for bioenergy assessment methodology that could be taken up by the authorities with a relatively small effort. If such a single 'core' assessment method is accepted the results could then be easily aggregated to European level allowing for a much more accurate comparison between the Member States and also a very accurate estimation of potentials for Europe as a whole.

In order to reach this objective a careful review has been necessary as to what elements of the general biomass assessment framework are suitable for harmonisation, requiring some rather difficult compromises. The Consortium implemented a focused and pragmatic work plan where the ultimate goal was to propose a specific core method as opposed to simply reviewing the various possibilities.



The methodology described in this document is based on the above three pillars, used as a best possible compromise. This proposed assessment framework is neither the most sophisticated, nor is it the most comprehensive approach currently available. The advantage is that it could be readily adopted by the authorities of the member states allowing for comparable information from all over Europe, while keeping the possibility of conducting more comprehensive bioenergy studies on a local scale.

Clearly CEUBIOM was not set up with the purpose of taking over the entire task of providing answers to the challenges of biomass harmonisation in the EU and several constraints regarding the level of support this project can give to ongoing efforts. The two main constraints of CEUBIOM are:

- The project was submitted to a specific call for proposals that focused on the Western Balkan Countries. This means that the specific user requirements of these countries have had a significant weight in the formulation of the CEUBIOM methodology. If user requirements were to be updated by the requirements of several additional EU Member states then the proposed methodology should also be tailored accordingly.

- The project was formulated according to the call objectives having a very strong emphasis on the integration and explicit use of Earth observation data. Accordingly, a spatially-explicit method was formulated with all the constraints that come with such an approach. In practical terms it means that the methodology described here places a lot of weight on the cost efficient derivation of the initial theoretical potential (using EO data) and

somewhat less focus on the subsequent processing of this information into specific bioenergy potentials.

The intention of the CEUBIOM Consortium is to provide a deliverable that describes the workflow of the proposed approach and provide enough details so that it could be used in the formulation of a detailed Terms of Reference for the methodology to be implemented in European countries. A great advantage of such a workflow approach is that additional requirements (if they are fit for harmonisation) could also be integrated at a later stage. This should also serve as an answer to the first constraint.

The methodology framework proposed by CEUBIOM could be considered a "core" part in any bioenergy assessment activities that may take into account technical feasibility, economic, environmental, socio-political and other constraints. Only this "core" part is proposed for harmonisation resulting in datasets that will be comparable and available for European level aggregation. Naturally users may still have any number of specific requirements and they may request any number of specific boundary conditions to be taken into account. These constraints fall outside the scope of CEUBIOM and they are not considered for harmonisation.

The benefit of the CEUBIOM proposal for harmonisation is that two important requirements are met simultaneously.

- On the one hand key elements of national bioenergy-related information will now be generated in a uniform, harmonized manner all over Europe allowing for an easy aggregation of this data to European level and thus directly supporting relevant decision and policy making processes, and

- On the other hand the proposed approach will allow for the subsequent integration of any national (or regional) priorities and the considerations of any number of environmental, technological, legal, social, economic, etc constraints that otherwise would be very specific to a particular country or region.

Elements of this harmonized 'core' framework could change as a result of expert discussions but it is the proposal of the CEUBIOM consortium that this overall approach be implemented as a general concept for harmonisation.

1.1. Terms & Definitions

In terms of terminology CEUBIOM has generally adopted FAO' Unified Bioenergy Terminology [FAO, 2004] and definitions[3]. Whenever a different term is used or there are ambiguities it is always indicated in all CEUBIOM documents and reports.

For the sake of providing a quick guide to any non-expert reader some key terms and definitions are briefly discussed below.

Biomass

Different definitions of biomass can be found in the literature, some of them are given below:

[3] http://www.fao.org/docrep/007/j4504e/j4504e00.htm#TopOfPage

- **Biomass** - material of biological origin excluding material embedded in geological formations and transformed to fuel (CEN TC 335 – Solid Biofuels)

- **Biomass** means the biodegradable fraction of products, waste and residues from biological origin from agriculture (including vegetal and animal substances), forestry and related industries including fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal waste; (RES Directive 2009/28)

- **Biomass** means nonfossilized and biodegrable organic material originating from plants, animals and micro organisms. This shall also include products, by-products, residues and waste from agriculture, forestry and related industries as well as the nonfossilized and biodegrable organic fractions of industrial and municipal waste (Biomass in Commission Decision 29/01/2004 Guidelines for monitoring and reporting greenhouse gas emissions)

Renewable biomass

According to UNFCCC (Annex 18), biomass is 'renewable' if one of the following five conditions applies:

1. The biomass is originating from land areas that are **forests,** where:
   (a) The land area remains a forest; and
   (b) Sustainable management practices are undertaken on these land areas to ensure, in particular, that the level of carbon stocks on these land areas does not systematically decrease over time (carbon stocks may temporarily decrease due to harvesting); and
   (c) Any national or regional forestry and nature conservation regulations are complied with. The forest definitions as established by the country in accordance with the decisions 11/CP.7 and 19/CP.9 should apply.

2. The biomass is **woody biomass** and originates from **croplands and/or grasslands** where:
   (a) The land area remains cropland and/or grasslands or is reverted to forest; and
   (b) Sustainable management practices are undertaken on these land areas to ensure in particular that the level of carbon stocks on these land areas does not systematically decrease over time (carbon stocks may temporarily decrease due to harvesting); and
   (c) Any national or regional forestry, agriculture and nature conservation regulations are complied with.

3. The biomass is **non-woody** biomass and originates from **croplands and/or grasslands** where:
   (a) The land area remains cropland and/or grasslands or is reverted to forest; and
   (b) Sustainable management practices are undertaken on these land areas to ensure in particular that the level of carbon stocks on these land areas does not systematically decrease over time (carbon stocks may temporarily decrease due to harvesting); and
   (c) Any national or regional forestry, agriculture and nature conservation regulations are complied with.

4. The biomass is a **biomass residue** and the use of that biomass residue in the project activity does not involve a decrease of carbon pools, in particular dead wood, litter or soil organic carbon, on the land areas where the biomass residues are originating from. For

example, if bagasse from sugar production would in the absence of the CDM be dumped or left to decay and is used for energy generation under the CDM, it can be assumed that the use of the bagasse does not affect the sugar cane cultivation practices and hence the carbon pools of the respective region.

Biomass residue is defined as biomass by-products, residues and waste streams from agriculture, forestry, and related industries. In contrast, where a CDM project involves the collection of dead wood from a forest, which would not be collected in the absence of the CDM, the extracted biomass cannot be regarded as renewable, since it would result in a decrease of carbon stocks.

5. Biomass is also the non-fossil fraction of an **industrial** or **municipal waste**.

'Any substance or object the holder discards, intends to discard or is required to discard' is WASTE under the Waste Framework Directive (European Directive (WFD) 2006/12/EC), as amended by the new WFD (Directive 2008/98/EC, coming into force in December 2010). Once a substance or object has become waste, it will remain waste until it has been fully recovered and no longer poses a potential threat to the environment or to human health (from: http://aggregain.wrap.org.uk/waste_management_regulations/background/definition_of.html).

Otherwise, where none of these conditions applies, the biomass is considered as *'nonrenewable'*.

Biomass considered in **CEUBIOM** is the **renewable, biodegradable fraction of products and residues from biological origin from agriculture (including vegetal but excluding animal substances), forestry and related primary industries excluding fisheries and aquaculture.** The biodegradable fraction of secondary industries or industrial and municipal waste have not been considered in this project.

Biomass potential

Regarding definitions of **biomass potentials,** international practice and standards were used within CEUBIOM. Estimations vary according to the calculation methodology and the assumptions made (e.g. land use patterns for food production, agricultural management systems, wood demand evolution, production technologies used, natural forest growth etc). In terms of **biomass potentials**, the following potential types are often discussed:

- **Theoretical potential**: the theoretical maximum potential is limited by factors such as the physical or biological barriers that cannot be altered according to the current state of science.
- **Technical potential**: the potential that is limited by the technology used and the natural circumstances.
- **Economic potential:** the technical potential that can be produced at economically profitable levels.
- **Implementation potential:** the share of the economic potential that can be implemented within a certain time and under specific socio-political and economic conditions.
- **Environmentally sustainable potential**: the potential that takes into account ecological criteria, e.g. loss of biodiversity or soil erosion.

The classification of a methodology strictly into these categories is often difficult, since there are overlaps between the potential types. It is also more important to clearly define the boundary conditions and assumptions made than to categorize. **Thus, the suggested assessment protocol in CEUBIOM can not clearly be categorized into any of the above mentioned potential types, but is rather a mixture of technical, environmentally sustainable and to some extent implementation potentials that suit the needs of the project endusers**.

The term 'frame conditions' include all basic conditions and assumptions, that have to be made in order to move from the theoretical potential to another potential.

Bioenergy

Bioenergy comes from any fuel that is derived from biomass - recently living organisms or their metabolic by-products. Unlike other natural resources such as petroleum, coal and nuclear fuels, bioenergy is a renewable energy source. Like all methods used to generate energy, the combustion of biomass generates pollution as a by-product. However, because the carbon in biofuels was recently extracted from atmospheric carbon dioxide by growing plants, the combustion of a biofuel does not result in a net increase of carbon dioxide in the Earth's atmosphere.

Apart from the above mentioned definition of bioenergy, there are many other definitions of bioenergy with some of them listed below:

Bioenergy is defined as energy from biomass or peat (usual word used for energy associated with biomass).

Bioenergy refers to the technical systems through which biomass is produced or collected, converted and used as an energy source.

Bioenergy is energy of biological and renewable origin, normally derived from purpose-grown energy crops or by-products of agriculture.

The term **bioenergy encompasses** the overall technical means through which biomass is produced, converted and used.

Modern bioenergy refers to some technological advances in biomass conversion combined with significant changes in energy markets that allow exploring an increased contribution of biomass to be used for our energy needs, whether throughout traditional or emerging technological areas (e.g. from combustion to liquid biofuels).

For further reading on assessment methods and bioenergy definitions the reader is kindly referred to the international literature and the CEUBIOM e-learning tool at http://ceubiom.geonardo.com.

2. Objectives & User requirements

The aim of the CEUBIOM project has been to develop a harmonized approach for national-level biomass assessments for energy by combining terrestrial methods with remote sensing based applications with an emphasis on South-Eastern European and Western Balkan countries. The underlying reason for this work has been the fact that national results of national surveys often provide incomparable and heterogeneous results that are difficult to be used for consolidated actions or political decisions. Thus the harmonization of the methods/work processes is essential especially on a national/European level. Results include clear guidelines on how each country should undertake the biomass potential assessment in terms of input data, biomass types considered, area covered and methods and assumptions used in order to create a database which is comparable throughout Europe.

In this context CEUBIOM has aimed to assess the current practices in biomass assessment in order to develop a proposal for a harmonized method, which should be applicable and relatively easy to implement and in line with the assessed user requirements. Since the integration of remote sensing techniques gives a clear added value in terms of spatial information, it is a vital component of the method proposed by CEUBIOM. Therefore the project focused exclusively on the development of a proposal for a spatially explicit methodology, providing a uniform resource-focussed approach for the users.

The logical framework of CEUBIOM is that of a bottom-up approach (i.e. country level assessments), which then can be aggregated to a common European result; this approach provides detailed and potentially multi-purpose information. The aim has been to find the best compromise in terms of costs, feasibility and methods suitable for national users in order to achieve a common and comparable assessment for Europe.

The assessment procedure designed in this study is based on the user requirements collected in the considered countries. The users have been defined as the national ministries and national bodies, which deal with biomass and energy issues. In terms of ministries these are primarily the Ministries of Agriculture, Forestry, Environment, Energy and Economy. In terms of national bodies and agencies, these are for example environment agencies or energy agencies. As mentioned in the EURISY Position Paper on 'Creating sufficient user pull to secure the benefits of satellite services for society', *'Pioneering local or regional authorities, as well as SMEs, already use satellite information and services as innovative, high value-added tools for their work. However, the process of adoption of innovation can be accelerated with specific measures and incentives for end-users'* [EURISY, 2010]. Thus, there are users with the willingness to take up new technology, if it fits their need and possibilities. The detailed assessment of these needs and possibilities and earnest considerations are the prerequisite to user acceptance. According to the position paper, satellite service providers should then deal with aspects such as improved market mechanisms, better balancing of supply and demand as well as incentives for end-user engagement and covering of initial costs.

During the course of the project end-user requirements were duly assessed (see CEUBIOM Deliverable 4.1[4]). The main requirements are summarised as follows:

[4] CEUBIOM Deliverable 4.1 - Summary of country reports of requirements. Available on the project website.

a) Generate one basic potential with well defined frame conditions (assumptions and restrictions) applicable for many users. This basic potential can be further used for individual potential assessments of specific user requirements.
b) Full update every 3 - 6 years, whenever spatial data, e.g. core service products, are available. In addition, an annual statistical update without a synchronous update of the spatial component can only be done for agricultural biomass.
c) Existing – archived - data should be used in order to keep costs as low as possible.
d) The resulting potential should be to satisfy different purposes, as e.g. internal information, policy and planning, dissemination, reporting and maybe (lower priority) also for subsidies and subsidy control. Potentials with very specific frame conditions, which are only important or available in one country or region, cannot be considered.
e) The requested accuracy ought to be in the range of 80 – 85 %, whereas the errors should be documented transparently and traceable wherever possible.
f) It can be recommended to derive at least three main thematic classes, i.e. 'forest biomass', 'agricultural biomass', and 'other biomass'. Further differentiation should be done based on conditions for accuracy, time or costs as well as based on the existence of data (e.g. if from core services already hardwood/ softwood and crops/ permanent crops/ grassland is available).
g) The product should be a continuous GIS map ranging over a scale of 1:75.000 – 1:100.000. Vector data on NUTS levels can be generated from this base level.
h) The method should not be too complex and be accompanied by training. The processing time (without EO data pre-processing) ought to be in the time frame of 6 – 9 months.

The above user requirements are based on the communication with the project's stakeholders from the target countries. These requirements were then processed in the conceptual framework and constraints of CEUBIOM. Two different sets of frame conditions have been distinguished: first, frame conditions, which can be harmonized throughout Europe; and second, specific frame conditions, where local expert knowledge (including scientific studies and literature) is needed to generate a useful result. Such frame conditions are in general not transferable throughout Europe without loosing usability and accuracy in the results. Accordingly the resulting approach is that of a technical-sustainable bioenergy potential using 'snapshot' assessment, meaning that basically no future scenarios and projections are included. For this reason, the suggested assessment method will not take economic boundary conditions into account because they are subject to fast changes and speculative prognosis, which should be avoided in order to provide reliable accuracy information for the users.

Naturally, projections and various models are considered an important tool for decision making therefore special attention has been made to define the 'core' methodology in a way that it can support subsequent modelling and scenario analysis for various purposes. This work can be carried out on a regional, national or European level by utilising datasets that have been generated in a uniform manner. Some of this modelling work could directly be integrated into the framework of the CEUBIOM methodology, making the resulting biomass potential assessment a tool for future scenarios and more advanced assessments. For example: use the class 'grassland' and assume a percentage of 20 % of Miscanthus on these grasslands calculating the additional amount of biomass for energy from this.

Clearly if such a harmonized approach is to be implemented on a European level, additional user requirements may arise, which could result in changes in the requirements. The methodology itself, however, is believed to be versatile enough to be accepted as a baseline and to accommodate any reasonable changes in user requirements.

As mentioned before, the initial goal of the CEUBIOM project was to develop a single harmonized approach for European biomass assessment for energy with special emphasis on South-Eastern European and Western Balkan countries. During the course of the project work and especially when taking into account the user requirements such as costs, it turned out that the definition of a single approach will not be sufficient to satisfy all demands. To overcome this dilemma it was decided by the consortium to define two approaches, described individually for the following biomass types: forest biomass, annual crops, permanent crops, grassland and energy crops. The two approaches are the 'Basic approach' and the 'Advanced approach'.

In this document, the terms '**Basic Approach'** and '**Advanced approach'** are used when referring to the proposed methodology. The different complexity is mainly related to the level of integration (and also its sophistication) of remote sensing data and spatial manipulation methods while the general framework conditions, assumptions and terrestrial data mostly remain the same:

- The basic approach is defined in order to fulfil the user requirements mainly in terms of cost, thus providing options to integrate data produced for other purposes or in other projects in biomass for energy potential assessment. However, there are disadvantages to this integration, especially related to spatial thematic detail and to more frequent updates (e.g. in the agricultural sector).

- In order to avoid these disadvantages, the advanced approach is an alternative using more advanced remote sensing tools and methods as well as more detailed (and thus often also more costly) data. If the resources permit, the advanced assessment can be performed leading to a more detailed and possibly also more accurate result in both domains, namely agriculture and forestry.

3. Overall process

Terrestrial methods such as statistical surveys, ground measurements and questionnaires are frequently used to derive biomass potentials on different scales and for different types. However, there are some main drawbacks in using these methods: first, the location of the biomass or biomass potential is generally not defined, although statistics are given for specific administrative units, the distribution within a given unit is unknown. Second, the figures can not be checked for accuracy and third, the results are highly heterogeneous, if the persons involved are not well coordinated. A fourth disadvantage would be that remote and less accessible areas are often underrepresented in these studies than well developed regions, which could lead to biased results.

Remote sensing systems are currently being extensively used for assessing land cover and corresponding biomass potential. Various sensor types record different properties, thus advantages and disadvantages have to be considered precisely when using one specific system. The main advantage of remote sensing is that it provides a very cost efficient way to collect the required information at areas that are usually remote and poorly accessible. Analysis of remote sensing data is also the only practical approach to measure actual land cover and changes at national or international scales. Two main approaches can be differentiated when talking about biomass assessment from remote sensing:

a) indirect biomass assessment and
b) direct biomass assessment.

For **indirect biomass** assessment, remote sensing delivers the land cover class for a defined area and this information is then combined with information on biomass content of a certain land cover type. This biomass content information has to be derived by other means (e.g. through field work). In contrast, **direct biomass** assessment uses relations between the spectral signal of remote sensing data and the actual biomass content on the ground to directly estimate the biomass amount. Both approaches have advantages and disadvantages and they are both utilized within CEUBIOM depending on their suitability.

The combination of terrestrial and remote sensing methods can be considered as a powerful approach for a variety of reasons: lower costs, higher accuracy, better coverage, more spatial or thematic details, etc. Depending on these reasons, different combination methods can be recommended. The overall process with its main components is sketched in a very simplified manner in Figure 1. The main input components are the remote sensing products, the terrestrial (statistical) information, local expert knowledge (including scientific literature) and a set of boundary conditions.

Local expert knowledge (LEK) is needed in order to fill certain information gaps. These gaps cannot be filled by remote sensing products or statistics, because the required parameters/values change constantly in space and time. LEK includes scientific literature as well as knowledge on local and temporal conditions. LEK on local conditions can be more easily extracted from literature or would have to be estimated only once and can be re-used for the next assessment. In contrast, temporally changing parameters, such as the water content of plants, would have to be assessed and updated for each individual biomass assessment.

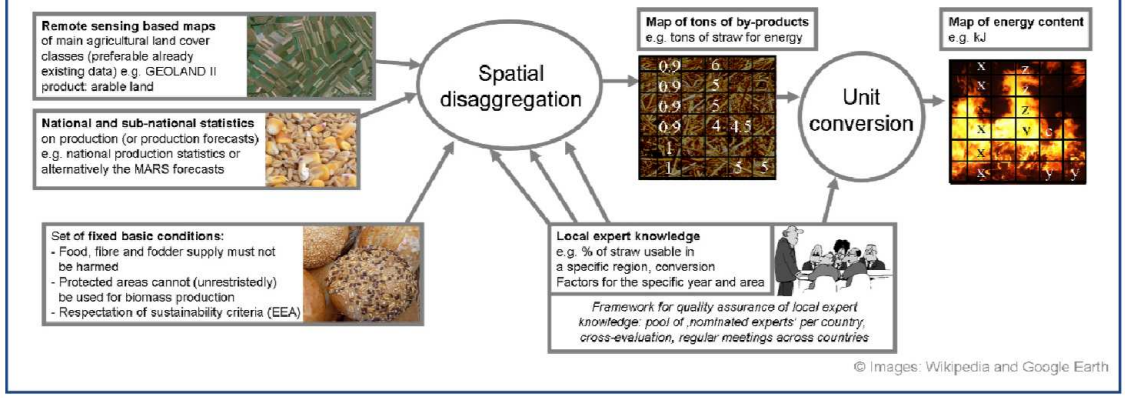


Figure 1: Simplified approach of using terrestrial and remote sensing data for biomass potential assessment for energy.

Based on the reasons mentioned before it was decided by the consortium to define two approaches, described individually for the following biomass types: forest biomass, annual crops, permanent crops, grassland and energy crops. The two approaches are:

- a **basic approach** and
- an **advanced approach**.

The **basic approach** is designed in order to fulfill most of the user requirements given in Chapter 2. This approach implies only a minor integration of remote sensing techniques, since the users require a method which is similar to their known procedures and they often do not have the capacity to do extensive remote sensing surveys. Since most users are interested in implementing the assessment in their own institutions, the latter is an important restriction. Thus, the basic approach is an indirect assessment using mainly existing land cover classification based on remote sensing data in combination with well established terrestrial surveys such as EUROSTAT. The added values of the basic approach compared to a simple statistical assessment as currently done in many countries (see Deliverable D3.1) are the following:

- **spatial dimension**: By including land cover maps, the potential can be geo-located and thus enable the stakeholders to obtain a more detailed view not only on the amount but also on the distribution of the biomass.
- **low cost**: The basic approach is designed to make optimal use of existing products and services at national and European level- meaning that this approach is relatively cheap.
- **fast implementation**: Since basically all input information is available through other projects or initiatives, the combination of these input data can be done quite fast.
- **harmonized data**: Although the basic approach strongly relies on local expert knowledge in order to guarantee the incorporation of local conditions, the use of a quality assurance system as suggested by CEUBIOM will significantly improve the harmonization.
- **Applicability** to all considered countries: The approach relies on existing information and thus it was checked, that all needed input data are available or can be substituted.

The main drawbacks of the basic approach are somehow also related to the advantages. As an example, the use of existing data as an advantage turns into a disadvantage in case this

existing data is not accurate or reliable. Thematic details of land cover maps are sometimes not detailed enough to accurately combine them with statistical data. In order to overcome the drawbacks of the basic approach, a more advanced approach in the inclusion of remote sensing methods is also developed.

The **advanced approach** contains a set of remote sensing options, which can be combined either in a direct or indirect assessment. Several options are given in order to give the user the option to pick the one that suits his/her data availability and knowledge best. More detailed and thus costly data is considered, such as LiDAR data or multi-temporal data sets. Furthermore advanced methods are suggested, which can only be applied by remote sensing experts and also might need longer processing time and thus increase the costs considerably. However, there are significant advantages using the advanced approach:

- **more thematic and spatial details**: Using target-oriented land cover classes instead of existing ones. Classes which are specifically selected for biomass for energy can be distinguished thus leading to a more detailed result. The use of more detailed data can also improve the classification accuracy.
- **independence from existing data**: Sometimes an independent assessment is needed, especially if existing initiatives are depending on political decisions and may be on hold for some time. In this case, the advanced approach is an independent and suitable alternative.
- **less local expert knowledge needed**: Generally the use of local expert knowledge is important in order not to ‘equalize’ circumstances, which are not equal in different countries and regions. However, the use of more advanced tools helps minimize the efforts for local experts incorporation and at the same time keeps the quality and (correct) heterogeneity of the output products.
- **faster updates**: In case of big projects, such as European-wide land cover maps or statistical assessments, the delivery time is sometimes quite long for the basic approach and the results might not be sufficiently up-to-date. With the advanced approach, national assessments can be done faster according to the specific temporal needs.

The advantages and disadvantages of the two approaches for the individual biomass types are discussed in detail in Chapter 8.

4. Frame Conditions

The flow of biomass potential assessment in general - and this applies also for biomass with special focus on energy – is to start from a theoretical potential and then coming to technical, ecological or sustainable potentials, and, finally to an economic/implementation potential (see schematic outline in Figure 2). However, as already mentioned in the introduction, the processing chain is not as straightforward as Figure 2 might suggest. In reality, the different potentials intersect and some frame conditions could be counted as restrictions in several steps. It is thus more important to clearly declare, which frame conditions are applied than to classify the potential into one of these categories. However, the theoretical potential is the foundation for all further calculations. It is important to mention that any error in the theoretical potential will be retained in all other potentials and also in the results of any applied modeling approaches.

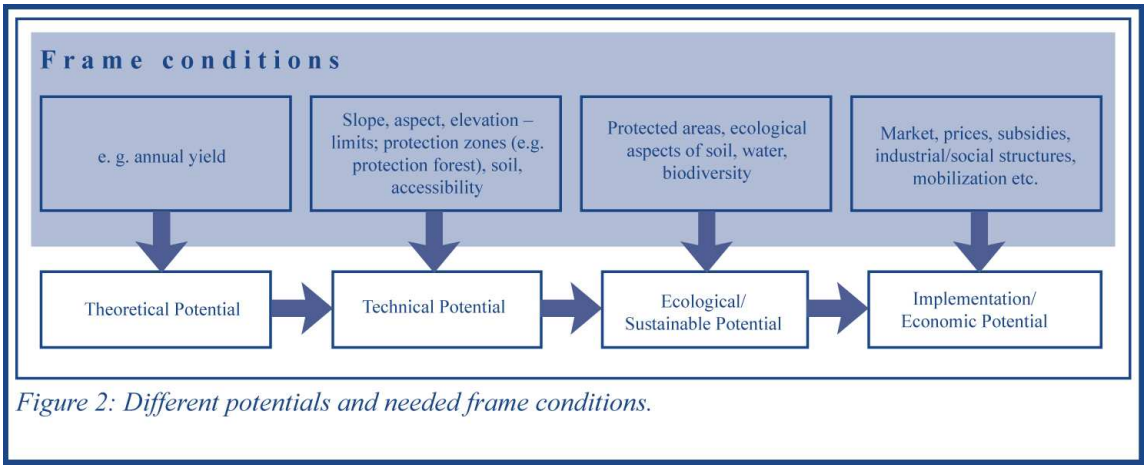


Figure 2: Different potentials and needed frame conditions.

In order to calculate the technical, ecological or economic potential, several restrictions and assumptions, often also termed as framework or boundary conditions are necessary. The frame conditions listed in Figure 2 are just examples, there can be many more.

According to the user requirements, we propose to calculate a technical-sustainable potential in a snapshot assessment, meaning that basically no future scenarios and projections are included. For this reason, the suggested assessment method will not take economic boundary conditions into account because they are subject to fast changes and speculative prognosis, which should be avoided in order to provide users with accuracy information of the potential assessment.

However, it is important to note that future projections are also needed for several purposes and they are important tools for policy decisions. Therefore, the resulting biomass potential assessment proposed by CEUBIOM can be used as basis for modeling future scenarios and other, more advanced assessments.

Two different sets of frame conditions can be distinguished: first, frame conditions, which **can be harmonized** throughout Europe; and second**, specific frame conditions**, where local expert knowledge (including scientific studies and literature) is needed to generate a useful result. Such frame conditions are in general not transferable throughout Europe without loosing usability and accuracy in the results.

Table 1 lists the general frame conditions, which is information needed for all biomass types. These are for example digital terrain models (DTM), soil information, accessibility information, etc.

DTMs can be used to derive elevation data or produce additional products such as slope maps and aspect maps (calculations see Equation 12 and Equation 13). Digital terrain models are available at high resolutions in many countries; possible data gaps can be filled using the globally available DTM from the Shuttle Radar Topography Mission (SRTM, [SRTM, 2008]). Soil maps are also available for most member countries and can be completed by European soil database.

In Table 2, Table 3 and Table 4, all specific frame conditions for forest-related biomass, agricultural biomass and other biomass (energy crops, grassland) are listed. For each frame condition, a classification of harmonizability is done and a summary of possible sources for all considered countries is given. In addition, it is assessed, whether the information can be available spatially and whether it is a technical, ecological or even a simple economic restriction.

Table 1: General frame conditions

Boundary condition	Harmo-nizable (yes/no)	Possible source (including substitute source in case of gaps)	Spa-tial	Tech-nical	Ecolo-gical	Eco-no-mic
Slope, aspect and elevation information	Yes	National DTM available in most countries, gaps can be filled with global SRTM model [SRTM, 2008]	x	x	-	-
Protected areas where no use is possible	Yes	Natura2000 area maps from EEA (http://www.eea.europa.eu/data-and-maps/data/natura-2000-eunis-database/natura-2000-eunis-database) Maps of national protected areas available for almost all countries (full coverage). Exceptions are Slovenia & FYROM where only point information is available	x	-	x	-
Protected areas with restricted use possible	Yes	Maps available for almost all considered countries (full coverage). Exceptions are again Slovenia & FYROM – in these countries, either no other protected areas except Natura 2000 exist or local experts/administrations have to be asked to locate the respective areas	x	-	x	-
Soil quality information	Yes	Soil maps available for whole territory in Hungary, Czech Republic, Poland and Slovakia Parts of the territory: FYROM, Bulgaria, Greece, Austria , Germany, Italy Statics with location (point-wise information only): BiH and Slovenia; Statistical figures: Romania, Croatia; Data gaps can be filled with the European soil database (http://www.eea.europa.eu/data-and-maps/data/soil-type)	x	x	x	(x)

Table 2: Agricultural frame conditions

Boundary condition	Harmonizable (yes/no)	Possible source (substitute in case of gaps)	Spatial	Technical	Ecological	Economic
Slope limits for different crops	No	Statistics available for Italy, Austria, Slovenia and BiH; Substitute by local and topographic expertise	x	x	-	-
Elevation limits for different crops	No	Partly statistics available, however, there might be several different values per country (according to region) Substitute by local and topographic expertise	x	x	-	-
Cultural/Social aspects	No	Difficult to assess – only from experienced biomass experts	-	x	-	x
Product-to-residue-ratios for different crops	Partly	Literature exists, however, values have to be updated by local experts according to climate conditions of the year, local conditions, type of seeds, etc.	x	x	x	x

Table 3: Forest-related frame conditions

Boundary condition	Harmonizable (yes/no)	Possible source (substitute in case of gaps)	Spatial	Technical	Ecological	Economic
Slope limits / elevation limits for forest harvesting	no	Absolute limitations from literature, difference depending on degree of mechanization – local expertise needed	x	x	-	-
Protection forest area (protection from avalanches etc) with restricted use	Yes	Available for: Austria, Czech Republic, Germany, Hungary, Italy, Poland, Romania, Slovakia, Ukraine and Slovenia Not available for BiH, FYROM, Greece, Bulgaria and Croatia For these gaps, it can either be assumed, that there are no areas of forest with protective functions or one has to rely on local expert knowledge combined with information on slope inclination and soil.	x	x	-	-
National forest inventory information including various topics (allometric equations, annual increment, etc.) Forest management plan (including for example sustainable level of volume, management practices, percentage of biomass above the sustainable level)	No	NFI and FMP available for all countries, but with different actuality (see details in Table)	x	x	x	x

Industry needs (residues, imports, exports, etc)	No	Partly from different industry statistics, to be filled up by local expert knowledge	-	x	-	x

Table 4: Grassland and energy crops - related frame conditions

Boundary condition	Harmoniz-able (yes/no)	Possible source (substitute in case of gaps)	Spati al	Tech nical	Ecolo-gical	Econo-mic
Amount of grass needed for fodder	N	Local expert knowledge	-	-	-	x
Amount of grass needed to be left on the ground (for ecological reasons, such as re-fertilization)	N	Local expert knowledge	-	-	x	-

There are some widely accepted general frame conditions, which also relate to the suggested harmonized approach.

1) utilization of forest biomass for energy can not interfere with use of forest fiber for industry (timber, pulp and paper)

There are three main reasons for this statement:

1) employment issues
2) transport issues
3) market (price) issues.

Employment is a sensitive issue in the wood-, pulp- and paper industry: if the industry can not be supplied with the needed raw material, industries might migrate to other countries. This is clearly a critical situation thus most countries are very specific in their frame condition to not touching the supply of industry.

A second issue is the ecological negative impact of long-distance biomass trade in order to supply the industry, if the raw material is not available in the close proximity any more. Recent examples in Austria show that pulp industry is now importing material from Chile in order to supply their demand. Due to increased use of biomass for energy the local supply chain has been cut.

A third reason is the current market and price influence on biomass use. A well managed forestry activity produces several kinds of wood products:

- Roundwood of several diameters and qualities (stems without treetops and branches).
- Roundwood is used in sawmills and the lower qualities in pulp mills and in the chipboard industry.
- Firewood (ready for the stove) is made from short cuttings, branches etc. Firewood is usually sold to private households for heating.
- Wood chips usually are chipped forestry rests as treetops and small branches. Wood chips are used as fuel in private or public buildings and in industries as fuel.

Processing roundwood in sawmills to joints and boards produces by-products such as sawdust (3-10 %) and industry wood chips (up to 25 %). Sawmill by-products are used as fuel or as industrial feedstock in the pulp and chipboard industry.

What is used as a fuel and what is used as an industrial feedstock can be a principal decision (What can be used as industrial feedstock should not be burnt!) or can also be seen as an economic issue (More expensive feedstock goes to industry, cheaper to energy use.
In Table 5, the situation is shown on the example of the well developed Austrian wood market (June 2010). In less mature markets the situation will be similar or more decisive (higher value for roundwood).

The figures that allow a comparison are on the left side (€/kg dry wood). All the figures for roundwood are for unchipped material, chipping cost vary from 0.02 to 0.08 €/kg dry wood, and have to be added to the cost per kg of roundwood. It can be seen, that forestry wood chips and industry wood chips are relatively cheap compared to roundwood and are typically used for energy purposes. Only the costs for poor qualities of industry roundwood (Industry II) are in the same range as wood chips.

Table 5: Comparison of cost for different wood qualities

Forest product	unit	€/unit	kg dry wood/unit	€/kg dry wood	Comments
Wood chips (fine)	1000 kg abs. dry	80	1000	0,08	3
Industry wood chips	m^3	10	150	0,07	4
Firewood	m^3	55	320	0,17	2
Roundwood industry I	Solid m^3	40	460	0,09	1, 3
Roundwood industry II	1000 kg abs. dry	60	1000	0,06	1, 3
Roundwood sawmills III	Solid m^3	53	460	0,12	1, 3
Roundwood sawmills II	Solid m^3	70	460	0,15	1, 3
Roundwood sawmills I	Solid m^3	110	460	0,24	1, 3
Roundwood color defects	Solid m^3	40	460	0,09	1, 3
Quality roundwood beech	Solid m^3	350	640	0,55	1, 3
Quality roundwood oak	Solid m^3	500	640	0,78	1, 3
Comments: 1 – unchipped (chipping cost=~0,02-0,08 €/t) 2 – ready for the stove, water content =~25% 3 – water content= ~30% 4 – water content=~50%					

Source: Own calculations based on published market reports for Austria (June 2010)

So for the biomass potential assessment it seems to make sense to concentrate on forestry products that cannot be used as a typical feedstock for industry. This means that roundwood is not to be considered as an energy source.

Sawmill by-products such as industry wood chips and sawdust can be (and are) used for energy as well as for industrial feedstock. A definition of a boundary (framework) condition is needed in this case (see second reason).

2) utilization of agricultural biomass for energy cannot interfere with use of agricultural products for food or livestock feeding

Example: In the RENEW project [Seyfried, 2008.], the amount of cereal straw, oilseed straw and maize straw were estimated and reduced by the amounts needed for animal feed or bedding and other fibre needs. Studies and recommendations like this can be used as frame conditions, however, they should be checked by local experts for their transferability and timeliness.

3) land in protection areas cannot (or at least not unrestrictedly) be used for biomass production

Example 1: The European Environment Agency (EEA) published a report on: 'How much bioenergy can Europe produce without harming the environment?' [European Environment Agency - EEA, 2006b]. In their prediction for 2030, they define the following key environmental (ecological) constraints, which are mainly considering agricultural land:

1) *The present share of 'environmentally orientated' farming would need to increase to about 30 % of the Utilised Agricultural Area (UAA) in most Member States, except for densely populated countries such as Belgium, Netherlands, Luxembourg and Malta where the agricultural land per head ratio is very small. In these countries, the necessary share was set at 20 % of UAA by 2030.*
2) *At least 3 % of currently intensively used farmland should be made available by 2030 for nature conservation purposes in order to re-create ecological 'stepping stones' to increase the survival and/or re-establishment of farmland species in these areas.*
3) *If in future extensive land use categories such as permanent grassland, olive groves and dehesas/montados are released from agriculture, and therefore become potentially available for biomass production, these should not be ploughed for targeted biomass crops. Instead they should be maintained under their current land cover and ecological structure, while biomass from grass cutting or tree pruning could be harvested for bioenergy production.*
4) *Biomass crops chosen for future bioenergy production should be selected carefully with respect to both their environmental pressures and their potential to positively influence the landscape and biodiversity quality of an area. The criteria for prioritising these crops on the basis of their environmental performance should involve effects on water, soil and farmland biodiversity.*

Example 2: Another EEA publication from 2007 is focussing on the environmentally compatible biomass for bio-energy from European forests [European Environment Agency - EEA, 2007a]. They considered protected areas, biodiversity, soil erosion and –compaction, site fertility and nitrogen inputs as parameters for boundary conditions in terms of sustainable and environmentally compatible potential. In addition, also an economic model was applied assuming a fixed price for wood chips and varying costs for extracting wood residues from the forest. More details on the model and model structure are given in [Kallio et al., 2004].

4) usage has to be sustainable, e.g. in a well managed forest, only the increment of forest biomass can be harvested.

Example: The Austrian Research and Training Centre for Forests, Natural Hazards and Landscape (BFW) carried out a study assessing the forest biomass in Austria commissioned by the Austrian Ministry of Agriculture and Forestry; ; see [Forschungszentrum Wald - BFW, 2008] and [Forschungszentrum Wald - BFW, 2009]. In these studies, different aspects such as sustainability and biodiversity, economic developments (five different scenarios) and four different silvicultural treatment scenarios were used to model the biomass until the year 2020.

5. Basic approach

The basic approach is designed primarily to satisfy the user requirements. It is largely based on statistical data, since this is the data currently used and accepted. The main added value of this approach compared to simple statistics is the spatial dimension. It is clear that the basic approach cannot satisfy all user needs, but it is a compromise in terms of costs and benefits. For the basic approach, special attention was given to data availability and feasibility of the method. Generally it can be stated, that not the most advanced tools and most recent data sets are used in the basic approach, but reliable and generally accepted ones.

5.1. Input data sets

The data used as input can be distinguished in terrestrial data and remote sensing based data. Typically, terrestrial data are statistics available for a point, a specified area or most frequently for an administrative unit. The following sections compile the existing and needed input data for biomass from forestry, agriculture (including grassland) and energy crops.

5.1.1. Terrestrial data sources

FORESTRY

For forest-related biomass, the main sources of terrestrial data available in most countries are the National Forest Inventory (NFI) and Forest Management Plans (FMP). Information on the availability of NFI and FMP data in the considered countries as well as the year of the last update and the sources are given in *Annex 7.1: Forestry data available for each considered 'CEUBIOM' country*'. From the NFI databases, information such as total volume (growing stock of stemwood over bark over a certain diameter) or calculated annual growth can be obtained both on a plot level as well as aggregated to (sub-) national statistics. Due to data confidentiality, the plot information with geo-location is often not publicly available. However, if the biomass assessment is done by the national authorities, this data should be available to the respective national entities. In contrast, the aggregated data is generally published in a report and can be used freely.

Important terrestrial information needed for the calculation of woody biomass for energy are the so-called '*biomass expansion factors'* (BEFs). BEFs describe the relation between growing stock and total biomass (above-ground and / or below-ground). In CEUBIOM, we use only above-ground biomass (see explanation above). Table in *Annex 7.1: Forestry data available for each considered 'CEUBIOM' country*' shows the availability of national specific BEFs in the considered countries. There are two alternatives to fill gaps:

1) to use the BEFs from a country and transfer it to the same bio-geographic region (e.g. use of the Polish BEFs also for Czech Republic) or
2) to use the IPCC-GPG default values for temperate forests (Source: [IPCC, 2006]).

Based on the NFIs and other national data sources, EUROSTAT provides statistical data on wood production and forestry (www.eurostat.ec.europa.eu). All data exists only at a national scale, no subdivision into NUTS 2 or NUTS 3 regions (see *Annex 1: NUTS regions of Europe*') is available. An overview on this data can be found in Table . The year of last update is given in the respective cell. All red cells represent data missing in EUROSTAT, mostly regarding non-EU countries in the Balkan region. In these countries data is available in from the national statistics. The sources for these national data sets are listed below the table.

AGRICULTURE

For agriculture, the terrestrial data sources mainly consist of the statistical agricultural data sets. They are available from different data centers at European level (EUROSTAT), national level and in some cases at regional level. All EU member states are required to report certain agricultural statistics to the EU. These data sets are published on the EUROSTAT website (http://epp.eurostat.ec.europa.eu) usually with a time lag of 1-2 years after the harvest. The most important statistics for agriculture biomass assessments are:

- production statistics
- area (land use) statistics
- yield statistics

These data sets can be found in the EUROSTAT database at:
http://epp.eurostat.ec.europa.eu/portal/page/portal/statistics/search_database
under: → 'Data Navigation Tree' → 'Data by Themes' → 'Agriculture, Forestry, Fisheries' → 'Agriculture/Regional agricultural statistics' → 'Areas harvested, yields, production'

EUROSTAT provides statistical data on NATIONAL level, NUTS-1 level and NUTS-2 level, but only if they have been provided by the national data centers. For some countries, statistical data is therefore not available at all administrative levels, as some countries e.g. do not have defined NUTS-1 regions (or they are equal to national level), and others have not delivered any data to EUROSTAT for several years. There is currently no NUTS-3 level data available through EUROSTAT.

Some of the CEUBIOM partner countries are not part of the EU and, therefore, no data is listed in the EUROSTAT database. For these countries it is necessary to contact the national data centers in order to obtain agricultural data on national, regional and department (or equivalent) level. These levels should be comparable to the NUTS regions used for EU countries. For the future, we recommend harmonizing the acquisition of agricultural data in these countries using the EU methodologies in order to obtain comparable data at equal spatial scales. In some countries this will already be the case. The non-EU countries are:

- FYROM
- Bosnia-Herzegovina
- Ukraine
- Croatia

As EUROSTAT does not include agricultural data at higher spatial resolution than NUTS-2 level, these more detailed data sets will need to be provided by the national data centers as well. More detailed spatially data will lead to more accurate results in the biomass assessments. Thus all partners were requested to check for available agricultural statistics. An overview of all available data sets at each specific administrative level (NUTS-3, NUTS-2, NUTS-1, national) for all countries is given in Annex 7:

<u>How to use the production and land use statistics?</u>

For most accurate results, information on production statistics and land use statistics for each crop type shall be used at the highest available level, e.g. NUTS-3 data (county/communal). This data is only available through national data centers (see Table). Where NUTS-3 data is not available NUTS-2 data (provincial/regional) shall be used instead etc.

When using the EUROSTAT data, one has to remember that the statistics are representative for one specific year. As a result of climatic conditions during the growing season and harvest

time both the production statistics and the yields of agricultural products can vary by a considerable degree each year. A biomass assessment based on yearly data is therefore also likely to vary significantly each year. If a yearly evaluation is needed, this effect is wanted and thus does not pose a problem. If an assessment is only carried out every 3-5 years, a different strategy might be needed. In this case, in order to overcome the yearly variations, we recommend using average values for each crop type for the last 3-5 years of data for each country/NUTS-region, whenever these are available from the statistics.

ENERGY CROPS

Based on CEUBIOM partner survey and our literature research, we can say that statistical information on energy crops (from statistical office, and ministries too) is generally very poor. Actually, there is no energy crops statistics separately within official statistics in any of the considered CEUBIOM countries. However, it is possible to find statistics for some energy crops for some countries. The results from our survey are very heterogeneous:

- in some countries it is possible to find the total amount of biomass used for energy, but not dividing between the different crops (for example, Germany and Austria),
- in other countries, there is no statistical information on energy crops at all (for example, Bosnia and Herzegovina, Bulgaria)
- in many countries, energy crops are not separately tracked and statistically evaluated (for example, Slovenia, Croatia)
- sometimes, there is more information available on energy crops from other sources (outside of statistical offices and ministry), but it is not reliable and not reproducible (for example, Austria)
- there is no specialized statistics on energy crops, and data from agriculture statistic or from statistic on bio fuels are not suitable for this purpose (for example, Czech republic)
- in Poland for example, there are data about the area of energy crops, but data about yields is currently still missing, although planned to be available this year
- in some countries, it is known even without energy crops statistics, that there is no large extent of energy crops such as SRC, but rather some pilot/demonstration areas
- the use of energy grasses is near zero in all countries (actually there are only some pilot /demonstration areas with these energy crops)

This survey shows the need for a common reporting system for energy crops within Europe, optimally including also non-EU countries in the Balkan region and Eastern Europe. It can be recommended to include Energy crops as a specific category into EUROSTAT.

5.1.2. Remote sensing/spatial data sources

The Deliverable on European and International Standards and Recommendations (CEUBIOM D2.3) already lists a variety of land use and land cover products at a European scale and analyses their advantages and disadvantages with respect to the use in biomass potential assessment for energy. The two main products for agricultural and forestry applications are CORINE Land Cover (CLC) and the GEOLAND2 core service products developed with the EUROLAND programme.

CORINE Land Cover is a geographic land cover/land use database encompassing most of the countries of the European Community and the majority of the Central and East European countries and parts of the Maghreb. CLC describes land cover (and partly land use) according to a nomenclature of 44 classes organized hierarchically in three levels. CLC was elaborated based on the visual interpretation of satellite images (SPOT, LANDSAT TM and MSS). Ancillary data (aerial photographs, topographic or vegetation maps, statistics, local knowledge) were used to refine interpretation and the assignment of the territory into the categories of the CORINE Land Cover nomenclature. The smallest surfaces mapped (minimal mapping units MMU) correspond to 25 hectares. Linear features less than 100 m in width are not considered. The scale of the output product was fixed at 1:100.000. Thus, the location precision of the CLC database is 100m. The main advantage of CLC is the detailed thematic differentiation into e.g. the different permanent crops (olives, vineyards, orchards), while the main disadvantage is the very coarse MMU of 25 ha.

One of the large projects in the European GMES initiative is the currently ongoing GEOLAND2 project (www.gmes-geoland.info). One part of this project is the component called EUROLAND, which develops operational methods to produce a high resolution generic land cover layer of Europe. The basic remote sensing data is SPOT and IRS. The main advantage of the GEOLAND2 land cover information products is their high spatial detail; the main disadvantage is the relatively coarse class definition.
Originally, GEOLAND2 high resolution land cover data was expected to have a MMU of 1 ha and covering 16 classes including arable land and permanent crops (see also Figure 2). During the project implementation, the procedures had to be changed. Currently (July 2010, phone communication with coordinator of GEOLAND-2) the priority within the GEOLAND consortium based on recommendations of the member states, the GMES bureau, EEA and EC is to focus on the most needed classes.. Thus, the main HR layers to be realized as part of the proposed content for GMES Initial Operations (GIO) will most probably have the following characteristics:

1) Imperviousness layer
2) **Forest laye**r including the crown cover density information,
3) **Grassland layer** with intensity information (for extensive vs. intensive usage) including natural grasslands and pastures
4) Wetlands
5) Water (with small water bodies)

The data will be pixel-based raster products with a MMU of 20m (pixel size of ‘Image 2006/2009’ satellite coverage). For the HR forest layer an elimination of forest patches smaller than 1 ha is foreseen. The differentiation of agricultural classes ‘arable land’ and ‘permanent crops’ is not a priority issue in the current discussion. Furthermore, the intention is not to produce discreet classes such as e.g. forest/non-forest, but continuous forest cover

percentages on a pixel level. This would allow the user of such a dataset to interactively apply a threshold on specific purposes, e.g. to use different forest definitions thus leading to customer defined forest/non-forest maps. The same applies for coniferous percentage instead of discreet coniferous/deciduous and mixed classes and also for crown cover as a density parameter. In essence, the output of the data can be very similar to the results of the previous idea, i.e. a forest map with pixel-based percentage of crown cover and species mixture.
Even after the completion of this European-wide mapping for the above mentioned five HR layers, there will be a high probability that in the following countries **spatial gaps** might remain:

- Ukraine
- Croatia
- FYROM
- Bosnia and Herzegowina (BiH)

In addition, thematic gaps with respect to biomass potential assessment for energy are information on arable land and permanent crops. Thematic gaps are always more difficult to deal with than spatial gaps, because of the risk of double-counting areas, if information comes from different sources. Thus whenever data sets from different sources are combined, a thorough GIS analysis has to be done in advance to avoid errors such as double-counting or missing areas. Table 6 summarizes the possible data sources taking into account the newest developments within GEOLAND2 and lists possible alternatives.

Table 6: Land cover information from different sources

Land cover information	Inside EU 27 - sources	Outside EU 27 - sources
Imperviousness layer	Geoland 2, Not needed	Not needed for CEUBIOM
forest layer	Geoland 2	National, JRC forest layer, CLC
grassland layer	Geoland 2	National/ CLC
Wetlands	Geoland 2, Not needed	Not needed for CEUBIOM
Water	Geoland 2, Not needed	Not needed for CEUBIOM
Arable land	National/ CLC/advanced approach	National/ CLC/advanced approach
Permanent crops	National/ CLC/advanced approach	National/ CLC/advanced approach

For non-EU countries, the following **alternative procedures for forest** can be proposed:

Alternative 1

For Croatia, FYROM, BiH as well as the rest of the Balkan region, the JRC forest area map and the forest type maps (http://forest.jrc.ec.europa.eu/forest-mapping/forest-cover-map/2006-forest-cover-map) could be used. Another option would be to use CORINE land cover (CLC), however due to the much more detailed minimum mapping unit, JRC forest maps should be preferred over CLC. The tree density map would have to be calculated as an additional processing step. For Ukraine, one possibility would be to calculate all three needed input data sets. The instructions on how to calculate these data sets can be found in Annex 3 and Annex 4.

Alternative 2

The second alternative would be to follow the advanced approach (see Chapter 6) for these countries.

Alternative procedures for agriculture ('annual crops' and 'permanent crops'):
Since currently GEOLAND2 might not distinguish between arable land and permanent crops any more (see five high resolution layers above) due to different priorities and limited resources within the project, the basic approach, which was designed based on previous information, needs slight updates with these new developments. There are two alternatives to obtaining this information:

Alternative A) Use of CLC for the differentiation
Alternative B) Use of national classifications

Using these two basic agricultural classes plus basic information on the percentages of different crops within each class, a basic spatial potential can be calculated without spatial differentiation of the crop types. This is a basic option, if no more information is available. However, the result is not very detailed. The crop classification scheme needed for accurate biomass assessment (see Table) would be much more detailed than the one available and would include, e.g. all cereals (wheat, barley, rye, oat…), sugar crops (sugar beet) and oil crops (rape, sunflowers) as individual classes

In order to obtain information on crop-distribution within the annual and permanent crops classes, two options are feasible:

1) Use national land use/cover classifications with more detailed thematic classes (e.g. LaND25 (Germany)). According to the partners' investigations, national classifications should be available from all partner countries, but their thematic and spatial resolutions may vary. If the classification classes and statistical data classes are not congruent, adaptations to the basic biomass assessment approach might be necessary in that some classes will need to be reorganized.
2) rely on local/regional experts to provide additional information concerning crop distribution

For crops changing repeatedly (catch crops), sometimes even 3 times a year, the first option is difficult to realize, since such up-to-date datasets are usually non-existent. For permanent crops such as vineyards, orchards and olive trees, specific classifications may exist in national land cover maps. Therefore, it is recommended to use such data whenever available. If not, the use of national or CLC classes with no further differentiation of permanent crops and arable land in combination with local expert knowledge is the second choice. The most simple and thus easiest procedure to implement is the third option, which is described in the basic approach presented in this document.

A general drawback in using existing land cover or land use classifications is the time gap between the satellite data acquisition and the timeframe for the statistical data. Pan-European classifications are only updated approximately every 5 years. The same is usually valid for most national land use classifications. Land use statistics though, are updated on a yearly basis for most countries. So land use statistics and land use area defined by the classification might not be equal leading to problems in the spatial distributions and minor errors in the accuracy of the final biomass values.

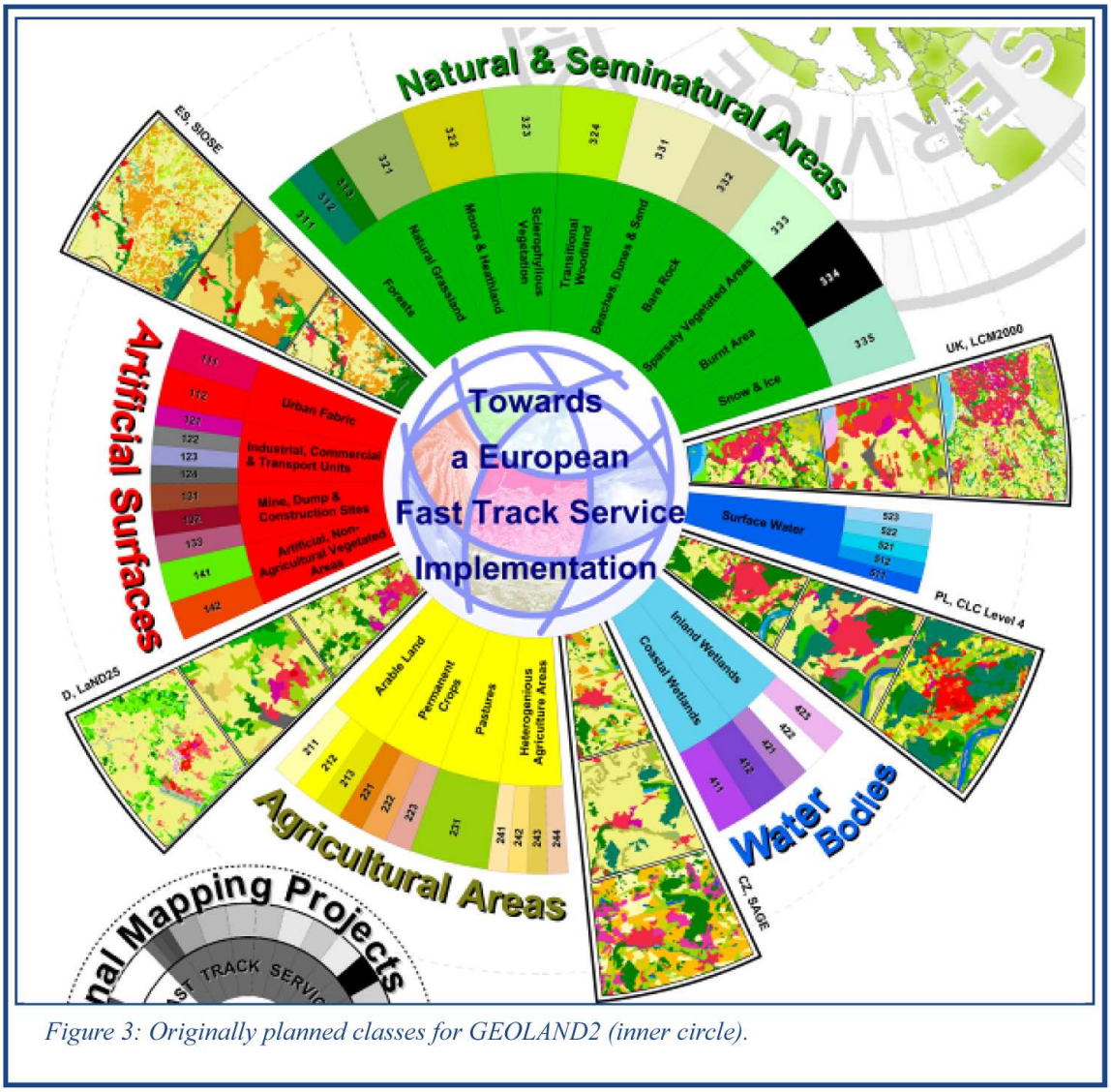


Figure 3: Originally planned classes for GEOLAND2 (inner circle).

ENERGY CROPS

There is no existing remote sensing product available for Europe, which specifically considers energy crops. Due to its small extent, SRC is typically part of the forest area mask in the large European products (GSE-FM, JRC, Geoland2 forest masks). Another problem is that SRC is often classified as forest area in the national statistics as well.

5.2. Forest biomass

Forest biomass for energy purposes as calculated in the suggested approach contains stemwood over bark (o.b.), branches, foliage (all considered from forests and forest plantations), by-products and residues from wood-processing industry.
Trees and tree residues outside forests / forest plantations are not considered in the basic approach.
In both, the basic and the advanced approach any type of recovered wood (e.g. from demolished constructions, furniture etc.) are not taken into account. Below-ground biomass is also not considered here. The reasons for not considering below-ground biomass are threefold:

1) Harvesting of below-ground biomass is not an option within this study due to high **harvesting efforts and costs**: The stump removal costs are variable and depend on status and characteristics of soil, stumps and roots (type of tree in terms of root system shape, stump diameter, etc.), removal technique (manually, with use of various stump-clearing machinery or explosives). Generally, tree stump removal involves a mix of these three techniques. Harvesting from a utilization of stump material point of view seems therefore to be a rather expensive endeavour. Only removal of oak (for tannin production) and pine (for resin production) are stated as economically justifiable, provided that the cost of transporting the stump material to the extraction plants is not exceedingly high [Forestry Encyclopedia, 1963]. Accordingly, for energy production, stump removal is generally not cost-efficient.
2) Harvesting below-ground biomass is also very critical for **two sustainability reasons**: loss of organic matter, fertilizers and stability. Extraction of below-ground biomass would remove valuable organic material needed to retain the fertility and structure of the soil. Another potential danger is related to steep slopes which significantly increase of risks such as landslides, avalanches and water/wind erosion. The removal of tree stumps facilitates the formation of gullies and torrents.
3) In some countries, harvesting of stumps and roots is **even prohibited** for ecological reasons mentioned above. Exceptions are land use change from forest to e.g. agricultural land, which is not very common nowadays in Europe.

The investigations on orchards and olive groves are considered in the agricultural approach.

It has to be mentioned, that in the **basic approach** we assume that the amount of biomass is based on statistical figures, which are assumed to be correct (e.g. EUROSTAT). Remote sensing is primarily used to give the figures a spatial dimension, i.e. to show the result as a spatially explicit map.
The **advanced approach** in contrast uses terrestrial information at another level and integrates the remote sensing data in a more analytical way. This means that the advanced approach does not necessarily lead to the same results in terms of biomass values as the national statistics and the basic approach.

The basic approach is shaped in order to make optimal use of existing data and products. The processing chain is sketched in Figure 4 and described later on in this section.

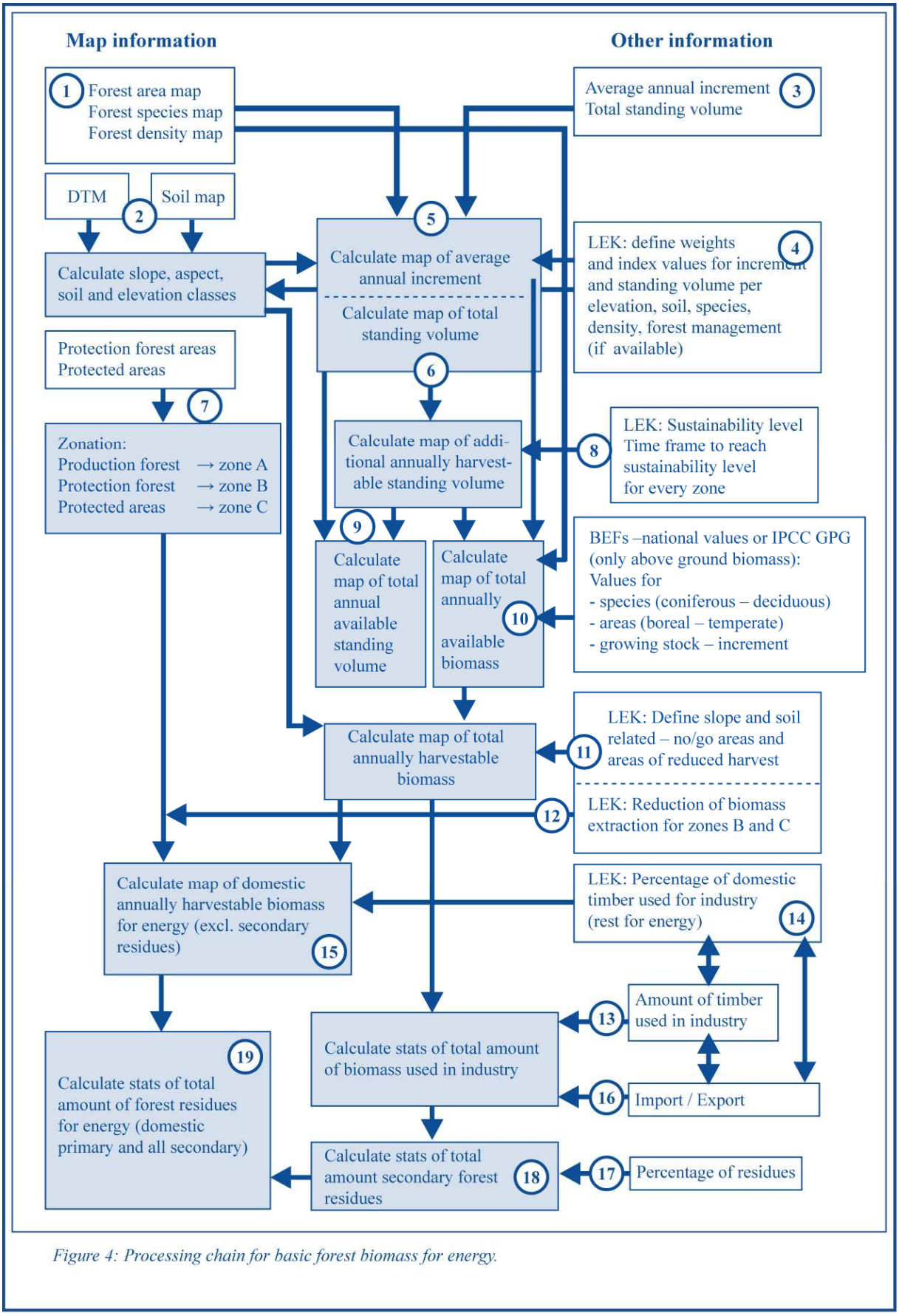


Figure 4: Processing chain for basic forest biomass for energy.

1) Take the **forest area map** including **species** and **density/crown cover** information derived from remote sensing data (from GEOLAND II core services or from JRC or from CLC)

→ see detailed explanation about the calculation of the remote sensing basic products above.

2) Use national **soil map** and national digital terrain model (**DTM**), fill gaps with European soil maps and SRTM DTM. Calculate slope and aspect from DTM as described in *Annex 6: Calculation of Slope and Aspect.*

3) Use statistics about **net annual increment** (NAI) and **total standing volume** of forest biomass– basic figures from EUROSTAT and national NFI databases.
   NAI: m³ over bark (total amount per country)
   Total standing volume: m³ over bark (total amount per country)

4) Use **local expert knowledge** to give index weights for the increment and the standing volume per elevation, soil, species (coniferous and deciduous only) and density. There is already a large variety of scientific literature available for several of these issues, however in order to ensure the best available data is used, the scientific literature has to be complemented by the local experts. Following outputs will be created:

   A) Table of **weights** (Table 7) for average annual increment for the following different parameters (W_{Parx})
   - elevation/altitude
   - soil type (classes)
   - species (coniferous/deciduous)
   - density / crown cover
   - forest management regimes, if available

   The weights always have to sum up to 1.

Table 7: Example for weights of the different parameters given by the local experts (cursive are exemplary values).

Parameter	Weight
Elevation	*0.15*
Soil	*0.2*
Species	*0.2*
Density	*0.05*
Forest management regimes	*0.4*
Sum of weight **must be equal 1!**	

   B) Table of **index values** (Table 8) for each parameter class ($Index_{classx}$: elevation class/ soil class/ species class/ density class/ forest management class)
   The values for each index should range from 0 to 1. An index 0 represents the worst case, i.e. very bad growing conditions, while an index value of 1 represents the best case.

Table 8: Example for index values given by the local experts for each of the parameters and each parameter class (cursive are exemplary values).

Parameter Elevation	Index
High elevation	*0.2*
Low elevation	*1*
Sum of indexes **does not have to be 1**	

An example of the use of the index values is given in Table for NAI in relation to soil quality; yellow are the local expert inputs.

5) Calculate a **map of average annual increment** ($avNAI_{pix}$)

Example calculations in Table and Table:

Red: Inputs from statistics (NAI = 1000 m³)

Turquoise: Inputs from soil map/ elevation classes: Pixels per class

Dark green: Input from forest area map: Total no. of pixels with forest = 100

Yellow: Local expert knowledge

The details on how to calculate the values is given below Table 9 and Table10.

Table 9: Example calculation NAI in relation to soil quality.

Soil	Forest area (pixels)	$Index_{classx}$ (0 = worst; 1 = best soil, no unit)	Intermediate result (no unit)	MF calculation (no unit)	$avNAI_{soil}$ per pixel per class (tons)	Total NAI per class (tons)
Permanently wet soils ($_{ws}$)	5 pixels $area_{WS}$	0.2 $index_{WS}$	1 PI_{WS} = $area_{WS}$ * $index_{WS}$		4.4 tons $avNAI_{WS}$ = MF * $index_{WS}$	22 tons NAI_{WS} = $avNAI_{WS}$ * $area_{WS}$
Sandy soils ($_{SS}$)	10 $area_{SS}$	0.2 $index_{SS}$	2 PI_{SS} = $area_{SS}$ * $index_{SS}$		4.4 $avNAI_{SS}$ = MF * $index_{SS}$	44 NAI_{SS} = $avNAI_{SS}$ * $area_{SS}$
Shallow soils ($_{ShS}$)	8 $area_{ShS}$	0.5 $index_{ShS}$	4 PI_{ShS} = $area_{ShS}$ * $index_{ShS}$		11 $avNAI_{ShS}$ = MF * $index_{ShS}$	88 NAI_{ShS} = $avNAI_{ShS}$ * $area_{ShS}$
All other soils ($_{oth}$)	77 $area_{oth}$	0.5 (if no info available: assumption = average)	38.5 PI_{oth} = $area_{oth}$* $index_{oth}$		11 $avNAI_{oth}$ = MF * $index_{oth}$	847 NAI_{oth} = NAI - ∑(NAI_{WS}, NAI_{SS}, NAI_{ShS})
Total	100 total forest area		45.5 Sum of pixels by index SPI =∑(PI_x)	~ 21.9 Multiplication factor MF = NAI/SPI		1000 NAI (total NAI per country)

Table 10: Example calculation NAI in relation to elevation.

Elevation	area (pixels)	$Index_{classx}$ (0 = worst; 1 = best soil)	Intermediate result (no unit)	MF calculation	$avNAI_{elevation}$ per pixel per class (tons)	Total NAI per class (tons)
High elevation ($_{HE}$)	40 $area_{HE}$	0.2 $index_{HE}$	8 PI_{HE} = $area_{HE}$* $index_{HE}$		2.94 $avNAI_{HE}$ = MF * $index_{HE}$	118 NAI_{HE} = $avNAI_{HE}$ * $area_{HE}$
Low elevation ($_{LE}$)	60 $area_{LE}$	1 $index_{LE}$	60 PI_{LE} = $area_{LE}$* $index_{LE}$		14.7 $avNAI_{LE}$ = MF * $index_{LE}$	882 NAI_{LE} = $avNAI_{LE}$ * $area_{LE}$
Total	100 total forest area		68 Sum of pixels by index SPI =∑(SPI_x)	~ 14.7 Multiplication factor MF = NAI/SPI		1000 NAI (total NAI per country)

Under the assumption, that both factors (soil and elevation) influence the NAI in the same extent (weights: 0.5/0.5), the calculation for each pixel is done ($avNAI_{soil}$ + $avNAI_{elevation}$) / 2

A pixel in the low elevation with a shallow soil would thus be calculated:
$(avNAI_{ShS} + avNAI_{LE}) / 2$
i.e. (11+14.7)/2 = 12.85

In case of different weights (W_{Parx}) for the different influencing parameters (soil, elevation, etc.), the following equation applies:

$$\mathbf{avNAI_{pix} = \sum(avNAI_{Parx} * W_{Parx} * No_{inPar}) / No_{inPar}}$$

where
$avNAI_{pix}$= average net annual increment per pixel
$avNAI_{Parx}$ = average net annual increment per pixel in parameter x
W_{Parx} = Weight of parameter x
No_{inPar} = Number of input parameters

Equation 1: Net annual increment per pixel

Note that the weights have to be between 0 and 1 and have to sum up to 1.

Example:
Under the assumption, that the soil influence is 30% and the elevation influence is 70%, a pixel in the low elevation with a shallow soil would be calculated:
No_{inPar} = 2 (soil, elevation), W_{soil} = 0.3, $W_{elevation}$ = 0.7

$(avNAI_{ShS} * W_{soil} * No_{inPar} + avNAI_{LE} * W_{elevation} * No_{inPar}) / No_{inPar}$
$(11 * 0.3 * 2 + 14.7 * 0.7 * 2) / 2 = 14.91$

6) Calculate a **map of total growing stock** of forest biomass (TGS)

The same system applies as for point 5) see Equation 2→ result is a map with total growing stock per pixel ($avTGS_{pix}$). This calculation is basically done in the same way as the calculation of $avNAI_{pix}$.

$$\mathbf{avTGS_{pix} = \sum(avTGS_{Parx} * W_{Parx} * No_{inPar}) / No_{inPar}}$$

where
$avTGS_{pix}$= average net annual increment per pixel
$avTGS_{Parx}$ = average net annual increment per pixel in parameter x
W_{Parx} = Weight of parameter x
No_{inPar} = Number of input parameters

Equation 2: Total growing stock of forest biomass per pixel

7) Overlay with **protected areas map** (Natura 2000 from EEA and national protected areas from national data sources) as well as with **zones of protection forest** (forest used as protection against avalanches etc. if existing) and divide the forest area into three zones:
   Zone A: 'production forest area'
   Zone B: 'protec**tion** forest area' (if existing) and
   Zone C: 'protec**ted** forest area'
   Core areas of protected forests (zone C), where no harvesting is permitted should be removed from the map as no-potential areas. However, there are protected areas, where forest harvesting is allowed and often needed. Those areas can be kept but have to be treated separately, since different amounts of biomass for energy percentages will apply in a later stage.
   Areas of protection forests (zone B) have to be considered in a similar way as the outer parts of protected forests. These areas have to be managed in order to sustain their protective functions. Although the amount of harvested timber and also residues is reduced compared to production forest, it should still be considered as a factor.

8) Use **local expert knowledge** and **forest management plans** to assess the 'sustainability level' ($SustLev_{zonex}$ in m^3 per pixel) and the 'time frame to reach this level' ($TimeLev_{zonex}$ in years) of forest growing stock in each of the three zones. The assumed 'sustainability level' and 'time frame' is needed for two different scenarios:
   a. *Scenario 1*: there is less growing stock in the forest than should be
   → part of the increment has to be left in the forest and cannot be harvested, the amount of increment left is depending on the time frame and on the increment
   b. *Scenario 2*: there is more growing stock in the forest than should be
   → in order to reduce the amount of growing stock, the total amount above the limit is divided by the time frame in years to reach the annual amount of additional harvestable volume. This is additional growing stock that can be harvested annually in addition to the annual increment.

$$\mathbf{AAGS_{pix} = (avTGS_{pix} - SustLev_{zonex}) / TimeLev_{zonex}}$$

where
$AAGS_{pix}$ = Additional annual amount of growing stock per pixel
$avTGS_{pix}$= Total growing stock per pixel
$SustLev_{zonex}$ = Sustainability level of zone x
$TimeLev_{zonex}$= Time to reach sustainability level of zone x

Equation 3: Calculation of the additional annual amount of growing stock

In Europe, Scenario 1 is not very common [MCPFE and FAO, 2003], thus all further explanations are based on Scenario 2. However, in case of Scenario 1, the values will be reduced instead of increased by the annual amount given, the procedure still remaining basically the same.

9) Add the annual amount of additional harvestable volume from step 8) to the annual increment values to generate the amount of **annually available standing volume** in all three zones.

$$TAAGS_{pix/zoneX} = avNAI_{pix} + AAGS_{pix/zoneX}$$

where
$TAAGS_{pix/zonex}$ = **Total annual amount of growing stock per pixel**

Equation 4: Calculation of total amount of annually available growing stock

10) Calculate the **above-ground biomass** based on
    a. the additionally annually available standing volume and
    b. on the NAI
    using first the *species-specific biomass expansion factors* and, second the *tree species maps*.

Due to high cost of extraction and probably a negative impact on the environment, especially on soil and soil biodiversity, the below-ground biomass is not to be considered as a biomass for energy source.
Use national BEFs, where available. The availability in the CEUBIOM countries has been assessed and is shown in Table . For countries missing national information (N/A in the table), the IPCC-GPG values [IPCC, 2006] for the respective region (boreal or temperate) can be used. Since all countries considered in CEUBIOM lie within the temperate region, these values should be applied.

→ the result of this step is a map of domestic annually available above-ground biomass (AGB_{pix} for all different purposes) and its sum (SAGB).

11) Use the **DTM** information, **soil map** and **local expert knowledge** to reduce the amount of biomass volume per slope and soil class. The total available above–ground biomass is thereby converted into extractable above–ground biomass.
    Examples are e.g. commonly used slope threshold of 40%, above which no harvesting is done due to high costs and soil erosion problems.

12) Use **local expert knowledge** to reduce the amount of extractable biomass from protection forests and protected areas (zones B and C) in the same way as in step 11)

    → result from steps 11) and 12) is a map of extractable above-ground biomass ($EAGB_{pix}$) **PRODUCT FM1**

13) Use **statistics** (EUROSTAT productions statistics, where existing, other countries can be filled up with national data, see Table), of timber needs for domestic wood, pulp and paper industry.

14) Use **local expert knowledge** to assess the amount of domestic woody biomass that is used for industry and what percentage remains for energetic use. An example of such local expert knowledge for Austria is given in Figure 3.

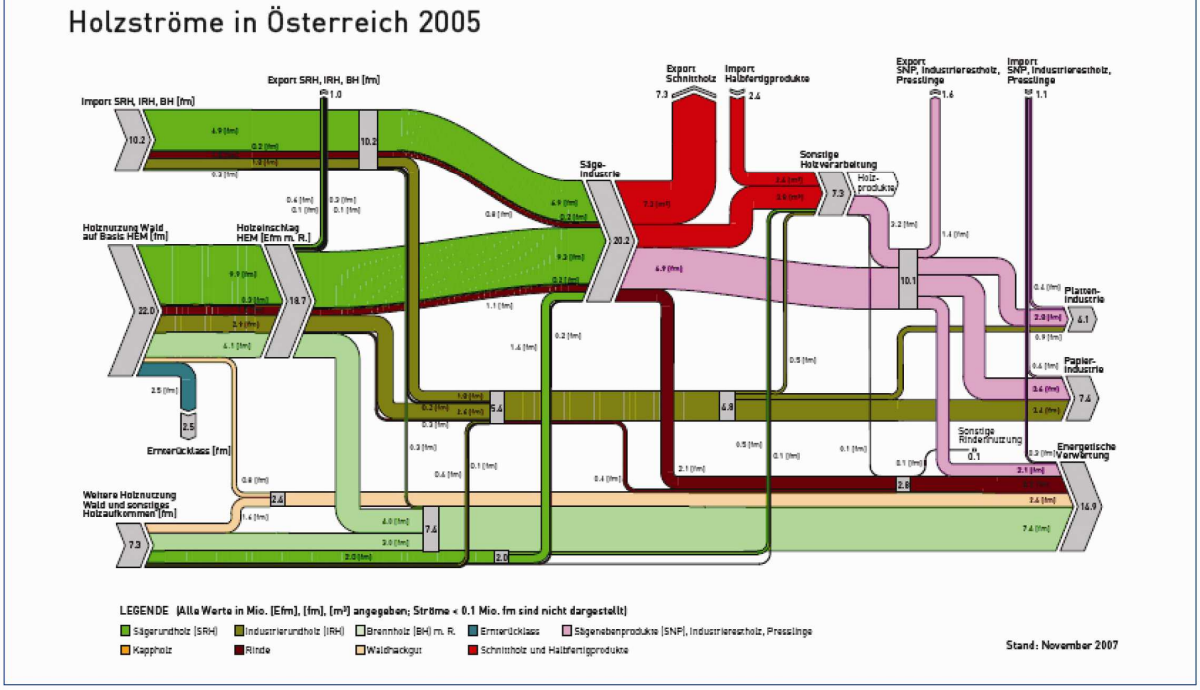


Figure 5. Timber/wood flow in Austria (from [Nemestothy, 2009])

15) Reduce the **amount of total domestic woody biomass** by the amount needed for industry and calculate a map of amount of domestic woody biomass for energy, i.e. areas with a high amount of total biomass will also have a high amount of biomass for energy.

16) Add/reduce the **amount of domestic industry woody biomass** with import and export statistics.

17) Obtain the percentages of **industry residues** for energetic use from statistics. Such statistics are available for Austria, Bulgaria, Germany, Italy, Romanian and Ukraine. For the remaining countries, local experts have to be consulted to obtain the percentage of residues from the total industry wood.

18) Calculate the **industry residues** for energetic use.

19) Add **industrial residues** for energy use to the domestic woody biomass for energy to obtain the total woody biomass for energy → **PRODUCT FS1**

Based on the amount of biomass available in tons, the energy content can be calculated. This issue is a specific topic dealt with in *Annex 5: Determination of the energy content of biomass*.

5.3. Agricultural biomass

This chapter deals with biomass potential assessments from agricultural residues from both annual crops and permanent crops and grasslands. Specific energy crops are considered separately in Chapter 5.4.

Crops:

There are two groups of agricultural crop types, which have to be handled differently:

- **annual crops:** Crops that are planted and harvested during the same production season, such as cereals, vegetables, etc.
- **permanent crops**: Crops that occupy the land for a long period of time and do not need to be replaced after each harvest, e.g. fruit trees, vineyards, etc.

Following our defined boundary conditions, we further distinguish two different types of agricultural residues of both crop types that can be used for bio-energy production:

Primary by-products are by-products or residues of agricultural crops, which
- accrue on the field, where the plants are grown;
- have a rather low energy density and
- are rather expensive to transport.

Secondary by-products are by-products or residues of agricultural crops, which
- accrue in a processing plant situated at a specific point location (plot);
- have a rather high energy density and
- are comparably cheap to transport.

To assess the potential of these by-products in terms of biomass energy it will be necessary to estimate the amount of e.g. straw (as the most important primary by-product in European agriculture) produced per area. This value will be dependant on the amount of land covered by straw producing crops, and the amount of straw that can be produced from these crops, as well as on the amount that will remain on the field to re-fertilize the soil. Sustainable management of agricultural land requires a part of the residues to remain on the land. This part of the residues cannot be used for bio-energy purposes. The amount left on the field depends on the fertility of the soil type and the required organic matter for the forthcoming crops planted. As a very basic approximation a so-called ‘sustainability factor’ of 0.25 is often used in statistical assessments.

It is also important to know the ‘product to residue ratio’ or specific ‘residue yields’ of a specific crop at a local/regional level. This information can only be obtained from local experts or from generalized statistical values found in agricultural literature. Literature values are usually not available at regional level and are generally less accurate than local expert information. Thus the values used should be based on general literature, but be checked for local adaptation needs and updates by local experts.

The potential of crop residues can then be estimated on the basis of cultivated area and residue yields for each specific crop:

$$FBP = \sum(CA * AP * PtR * Av)$$

where:

***FBP* = primary agricultural residues (e.g. straw, stalks), in tonnes**
***CA* = cultivated area of the crop, in hectares (ha)**
***AP* = agricultural production of the crop, in tonnes per hectare (t/ha)**
***PtR* = product to residue ratio of the crop**
***Av* = availability of residues for the crop according to current harvesting system**

Equation 5: Amount of primary crop residues

For orchards, olive groves and vineyards the yield or the land use area themselves are of little importance to estimate the amount of biomass for energy use from tree pruning. It is only useful when the number of trees or plants per hectare is known. Combined with an average statistical value of prunings per tree or plant type it is possible to estimate the overall residue potential per hectare for each of these crops. Information on residues per hectare or plant density is not available in the EUROSTAT or national statistics though and has to be provided by local experts in the basic approach. The advanced approach described in Chapter 6 overcomes these issues by providing estimates of tree/plant density.

When assessing the potential from agriculture, the crop itself is not of interest, as it is part of the second boundary condition, i.e. *'utilization of agricultural biomass for energy cannot interfere with use of agricultural products for food or livestock feeding'*. If a crop is specifically grown for energy purposes, it is described in the chapter on energy crops. In this chapter, the residues of the crops will be assessed. It is therefore important to know which and how many tons of residues accrue on the field and during processing of each crop. The classification of crops containing only primary or primary and secondary residues is given in Table 11. The crops and their major residues (primary and secondary) are provided in Table 12.

Table 11: Crops and major residues divided into primary and secondary by-products.

	Primary only	**Primary and secondary**
Annual	Corn, cereals, potatoes, sugar beets	Sunflower, rapeseed, rice
Permanent	Orchard, vinyards	olive groves, nuts

Table 12: Crops and major residues divided into primary and secondary by-products.

Crop	**Primary by-product(s)**	**Secondary by-product(s)**
Olives	Branches, grass	Pressing cake, stones (if olive oil is produced)
Sunflower	Stalks and leaves	Sunflower husks
Rapeseed	stalks	Pressing cake
Maize/Corn	Corn stover (stalks and leaves)	-
Vineyards/Wine	Branches	mash
Cereals (wheat, rye, barley, oat)	Straw, stalks	-
Potatoes	leaves	-
Orchards	Branches, grass	Pressing cake (only if fruit juice is produced)
Sugar beets	leaves	
Rice	Stalks and leaves	Rice husks
Nuts	Branches, leaves	Nut shells

The 'basic approach' is called basic as it relies on existing European remote sensing products and on available agricultural statistics to assess the biomass potential of different crops and on different spatial scales. Hence the RS component is a rather straight-forward and less time-consuming approach, standing in contrast to the more sophisticated 'advanced approach' described in Chapter 6. The methodology basically consists of spatially integrating statistical data with selected land cover classification results. The output is a map of total biomass for energy. It is based on agricultural statistical values of administrative units (NUTS) which are attributed to pixel via remote sensing based land cover classifications and product to residue ratios. These biomass-for-energy-maps therefore have a much higher spatial resolution as region based statistics. The overall accuracy of the spatial distribution is dependent on the thematic and spatial resolution, as well as the minimum mapping unit of the land cover classification used. The schematic system of the basic approach is shown in Figure 6. The final step of switching from biomass amounts to energy content by use of energy conversion rates is described separately in *Annex 5: Determination of the energy content of biomass*.

Local Expert Input:

Due to the very large regional differences in agricultural production methods and natural settings, many parameters for estimating the biomass potential will have to be defined by regional or local experts. Many agricultural parameters cannot be harmonized without falsifying the results. Thus harmonization should be understood in terms of harmonizing the methods, but not averaging values all over Europe.

The following table (Table 13) gives an overview of all local expert inputs which are needed or are advantageous for the calculation of the biomass potential from agricultural residues (excerpt from Table 29).

Table 13: Local expert knowledge needed for agricultural biomass assessment.

ID	Input short	Explanation	Example
A1	Index values for DTM derived parameters: elevation, slope and aspect. Needed for each crop type on local/regional scale	Each parameter can be subdivided into meaningful classes. The number of classes is open. For each class, an index should be assigned between 0 (no growing) and 1 (best growing condition).The sum of index values per parameter does not have to sum up to 1. No common unit definition applies.	Index values from 0-1 for each parameter and each crop
A2	Index values for soil parameters: Needed for each crop type on local/regional scale	Each parameter can be subdivided into meaningful classes. The number of classes is open. For each class, an index should be assigned between 0 (no growing) and 1 (best growing condition).The sum of index values per parameter does not have to sum up to 1. No common unit definition applies.	Soil index between 0-1 for each crop
A3	Local product to residue ratio for each crop	Each crop is attributed a local product to residue ratio depending on the plant physiognomy, on the crop quality, on the amount of e.g. straw left on the field and other parameters.	e.g. 1/4 (one 4th is agricultural crop product, 3/4th are residues)
A4	Conversion values for residue biomass to energy	The energy content for each residue (see separate list of residues) has to be evaluated. Average statistics exist in scientific literature,	Conversion value: e.g. kilojoules per

		but values may differ significantly locally. One important issue is the water content in the biomass, which significantly reduces the energy content per ton of biomass.	ton of biomass for each residue at administrative level x (NUTS-x)
A5	Conversion values for crop biomass to energy	The energy content for each crop (=agricultural product) has to be evaluated. Average statistics exist in scientific literature, but values may differ significantly locally. One important issue is the water content in the biomass, which significantly reduces the energy content per ton of biomass.	Conversion value: e.g. kilojoules per ton of biomass for each crop at administrative level x (NUTS-x)
A6	Plant/tree density information	Plants per ha. Needed for estimating the biomass from permanent crops	Plants/trees per ha
A7	Amount of residues in tons per plant/tree	Residues per plant/tree in tons. Needed for estimating the biomass from permanent crops	Tons of biomass per plant or tree
A8	Soil-related reduced extraction	These thresholds define restrictions of biomass extraction based on the soil types. Unit: percent of allowed extraction	Very shallow soils: no extraction Shallow soils: only 40% extraction All other soils: 80% extraction
A9	Sustainability factor	The sustainability factor defines how much biomass from primary residues must remain on the field for soil fertilization and sustainable production. ATTENTION: In case this value is already considered in the product to residue ratio (A3) this value must not be used again.	Expressed as a weight or percentage: Example: 0.25 or 25% of residues must remain on the field
A10	Weights for production values for each parameter: elevation, aspect, slope, soil, …	These weights determine to what extent all additionally used parameters influence the productivity of crop i at administrative level x. The weights must sum up to 1. No common unit definition applies.	Elevation: 0.2 Aspect: 0.1 Soil: 0.7 In this case the soil has the largest influence on productivity of crop i in region x.

Grasslands:

Grassland products are already used for energy production in a number of European regions. There are several forms of deriving bioenergy from grassland products, which include gasification, pyrolysis, hydro thermal upgrading (HTU) or biogas production and possibly the production of fuels for transportation. In Switzerland, the Netherlands, Germany and Denmark bio refineries which use grassland products have already been developed. In Germany the ‘surplus’ grassland biomass is locally used as an additional energy source. It has been shown that this ‘surplus’ grassland biomass can be used as either substrate for biogas plants or for combustion devices.

The main grassland products relevant for bioenergy are (EEA):

1. Fibres which are used for materials of thermal conversion for heat and electricity

2. Sugars, which are converted to bioethanol

However, there are yet only few studies focusing on bioenergy potentials specifically for grasslands. Several research studies clearly show that the usage of available grassland could prove to be a significant contributor to the energy mix used.
[Tilman et al., 2009] state that biofuels derived from low-input high-diversity (LIHD) mixtures of native grassland perennials can provide more usable energy, greater GHG reductions and less agrichemical pollution per hectare than corn grain ethanol or soybean diesel as they can be produced on agriculturally degraded lands and thus don't impact food production or weaken the biodiversity. The energy content of grassland products is estimated at 90 GJ per hectare per year.
In order to draw concrete and more straightforward policies in this aspect, further research is recommended. Systematic assessment of the available potential is required for the European region in order to obtain a good overview of the possibilities for economically and environmentally sustainable utilization of this type of biomass. CEUBIOM supports this need by defining a basic approach for grasslands and pastures, which is similar to the methodology used for the estimation of biomass energy from arable land crops. The approach will be based on the statistical data (from either EUROSTAT or the national statistical data centers) and land use classifications including grasslands as a separate class. Within the GEOLAND2 classification grasslands was always intended to be treated as an individual class. The new developments within GEOLAND2 suggest that this class will be subdivided into two grassland categories: intensive and extensive grasslands (always including pastures). Therefore, we recommend using this homogeneous GEOLAND2 classification as the main classification source once it has been implemented.

The method described in this chapter still relies on a general grassland layer, however, it can easily be adjusted for using two grassland classes classes by applying different LEK and statistical values. A classification with higher thematic resolution as currently envisaged by GEOLAND2 would then enable a more accurate approach, as the statistical data sets currently available are at a higher thematic resolution than the existing remote sensing based layers for grassland.

Currently EUROSTAT hierarchically lists the following classes for grasslands:

- Temporary grasslands and grazings
    - Grasses
    - Grazing

- Permanent grasslands (pastures and meadows)
    - Permanent meadows
    - Permanent pastures
        - Grasslands
        - Common pastures and heathland

Data on permanent grasslands and temporary grassland are available at national, NUTS-1 and NUTS-2 level for land use area. But for the more important production statistics (in tons per ha) data are only available at national level. For all subdivisions of temporary and permanent grasslands only data on national level is available through EUROSTAT. In some partner countries regional statistics will be available through the national data centers. The non-EU partner countries that are not listed in EUROSTAT all have at least national statistical data

available through their national data centers. An overview of available data through EUROSTAT is given in Table 8.

The methodology described in this chapter is based on the national grassland yield data available through EUROSTAT. If a higher spatial resolution is needed, regional yield data from national statistic centers can be used instead. The methodology remains identical.

Workflow:

The following paragraphs describe the processing workflow for all three agricultural biomass types (annual crops, permanent crops and grassland) in more detail. Three different processing schemes are distinguished depending on the type of crop:

1. 'Annual crop residues' for which production statistics and product to residue ratios are the most significant information. These crops include e.g. all cereals, potatoes, sugar beets, sunflowers, oil flax, dried pulses.
2. 'permanent crop residues' (i.e. vineyards, orchards, olive groves) for which the number of trees per ha and the amount of biomass per plant/tree is the most significant information.
3. 'grasslands' for which production statistics (and the amount/percentage needed for livestock fodder) are the most significant information.

Annual crop residues

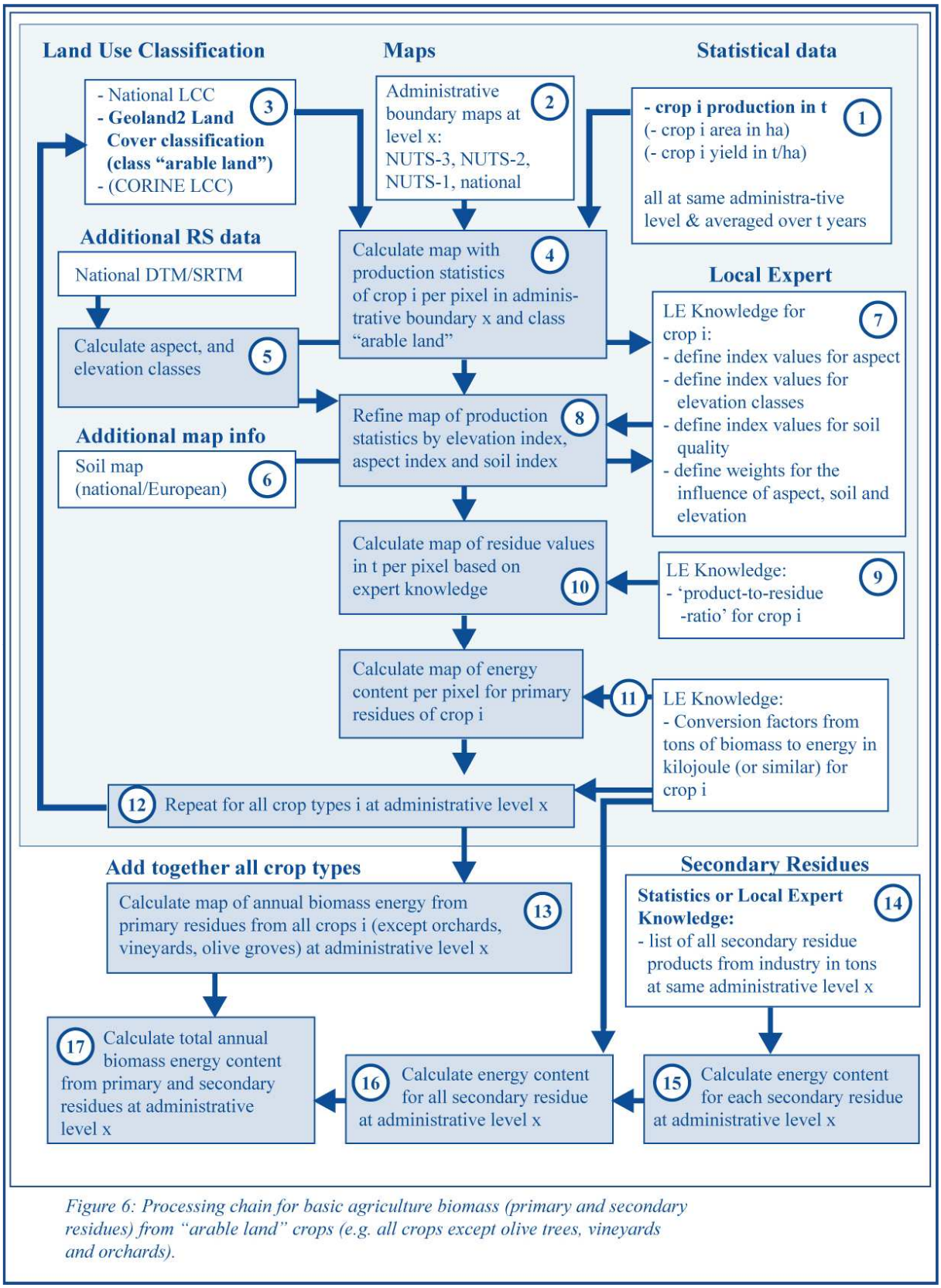


Figure 6: Processing chain for basic agriculture biomass (primary and secondary residues) from "arable land" crops (e.g. all crops except olive trees, vineyards and orchards).

1. Check the availability of agricultural **statistical data** for the required crops and at the highest level of spatial (administrative) resolution. The highest existing resolution should always be preferred. The hierarchy is as follows: NUTS-3 -> NUTS-2 -> NUTS-1 -> national data. All of the data should be at the same administrative level for each crop type. If the assessment is only carried out every few years, it is recommended to use average values for the selected time-period. For 'arable land' the most important statistical value is the 'total production value' per crop type (**TPV** $_{\text{crop I}}$).
2. Depending on the spatial level chosen for the agricultural statistics, the required NUTS boundary maps (shapefile) have to be downloaded from the related website (http://cidportal.jrc.ec.europa.eu/thematic-portals/agri4cast/).
3. Choose the **land cover classification** which best suits the agricultural classes from the statistics and which has the highest spatial resolution and is most up-to-date. In many cases this will be the national LCC. The CORINE LCC can also be used as remote sensing based input. The processing scheme in this document is based on the CORINE LCC, as it is comparable between different countries.
4. Data from 1), 2) and 3) are integrated in a **GIS** to create a production value of crop i for each pixel defined as class 'crop i' (if existing in LCC). Each production value for crop i in NUTS region x is first attributed to the corresponding spatial area defined by the NUTS region map. To further refine the spatial result, the integration with the LCC is followed. As most relevant crops in CORINE LCC fall under the class 'arable land', the production values of crop i among all pixels defined as 'arable land' will equally be distributed. Now each pixel defined as 'arable land' in CORINE LCC has been attributed a value calculated by Equation 6. In case the LCC only contains the class 'arable land' without any subdivision, each crop available in the statistics will be distributed to each 'arable land' pixel. This would result in multiple crop residues per pixel, which is certainly not true for one specific point in time, but reflects the situation over several years or – in case of catch crops – even over one year (see also step 13). Certainly, a subdivision into separate crop types would be beneficial; however, if this information is not available, it cannot be used in the basic approach. In case this information is crucial, the advanced approach should be used.

$$PPV_{crop\ i}(region\ x) = PS_{crop\ i}(region\ x) / NrPC_{arable\ land}(region\ x)$$

where

$PPV_{crop\ i}$ (region x) = Pixel production value of crop i in region x
$PS_{crop\ i}$ (region x) = Production statistic of "crop i" in region x
$NrPC_{arable\ land}$ (region x) = Number of pixels in class "arable land" in region x

Equation 6: Calculation of PPV for each crop and each pixel

5. From **DTM**, elevation classes and aspect maps (see Annex 6: Calculation of Slope and Aspect) can be derived, which are later used as input to set boundary conditions (threshold) by local experts.
6. National or European **soil maps** are integrated, which are later used as input to set boundary conditions.
7. Based on **local expert knowledge** several indexes (ranging form 0.0 (not suitable) to 1.0 (ideal)) are produced determining growing conditions depending on a) elevation criteria; b) aspect criteria; c) soil criteria. The soil index should follow the same classes used in the soil map.

The local expert has to define weights for each of the three parameters soil, aspect and elevation. These weights reflect the influence of each parameter on the crop growth. The values have to be between 0 and 1 and have to sum up to exactly 1.

8. The results of step 4 – the pixel based values – are now refined with the local expert defined indexes and weights. Each pixel is multiplied with an index value based multiplication factor, in such a way, that the overall agricultural statistics values do not change. An example of how to use a soil and elevation index is given below.
   Example: Calculation of refined production value per pixel and crop ($PPV_{crop\ I}$) with boundary condition indexes (soil and elevation).
   Red: Inputs from statistics
   (TPV = Total production value for crop i (e. g. $TPV_{crop\ I}$ = 1000 t)
   Turquoise: Inputs from soil map/ elevation classes: Pixels per class
   Dark green: Input from land cover map: Total no. of pixels with arable land = 100
   Yellow: Local expert knowledge

Table 14: Example calculation of refined production value per pixel and crop using soil boundaries

Soil	**area (pixels)**	**Index (0 = worst; 1 = best soil)**	**Intermediate result (no unit)**	**MF calculation**	**$avPV_{soil}$ per pixel per class = MF * Index**	**Total PV per class = $avPV_{soil}$ * area**
Permanently wet soils ($_{ws}$)	5 $area_{WS}$	0.2 $index_{WS}$	1 PI_{WS}		4.4 $avPV_{WS}$ = MF * $index_{WS}$	22 PV_{WS} = $avPV_{WS}$ * $area_{WS}$
Sandy soils ($_{SS}$)	10 $area_{SS}$	0.2 $index_{SS}$	2 PI_{SS}		4.4 $avPV_{SS}$ = MF * $index_{SS}$	44 PV_{SS} = $avPV_{SS}$ * $area_{SS}$
Shallow soils ($_{ShS}$)	8 $area_{ShS}$	0.5 $index_{ShS}$	4 PI_{ShS}		11 $avPV_{ShS}$ = MF * $index_{ShS}$	88 PV_{ShS} = $avPV_{ShS}$ * $area_{ShS}$
All other soils ($_{oth}$)	77 $area_{oth}$	0.5 (no info, e.g. assumption = average)	38.5 PI_{oth}		11 $avPV_{oth}$ = MF * $index_{oth}$	847 PV_{oth} = $avPV_{oth}$ * $area_{oth}$
Total	100 total arable land area		45.5 Sum of pixels by index (SPI) =∑(PIx)	~ 22 Multiplication factor (MF) = TPV/SPI		1000 TPV * (total PV_{cropI} per region in tons)

Table 15: Example calculation of refined production value per pixel and crop using elevation boundaries

Elevation	area (pixels)	Index (0 = worst; 1 = best soil)	Intermediate result (no unit)	MF calculation	$avPV_{elevation}$ per pixel per class = MF * Index	Total PV per class = $avPV_{elevation}$ * area
High ele-vation ($_{HE}$)	40 $area_{HE}$	0.2 $index_{HE}$	8 PI_{HE}		2.94 $avPV_{HE}$ = MF * $index_{HE}$	22 PV_{WS} = $avPV_{WS}$ * $area_{WS}$
Low	60	1	60		14.7	44

ele-vation ($_{LE}$)	$area_{LE}$	$index_{LE}$	PI_{LE}		$avPV_{LE}$ = MF * $index_{LE}$	PV_{SS} = $avPV_{SS}$ * $area_{SS}$
Total	100 total arable land area		68 Sum of pixels by index (SPI) =∑(SPIx)	~ 14.7 Multiplication factor (MF) = TPV/SPI		1000 TPV * (total PV_{cropI} per region in tons)

Under the assumption that both factors (soil and elevation) influence the TPV to the same extent (0.5/0.5), the calculation for each pixel is done by:

$(avPV_{soil} + avPV_{elevation}) / 2$

The value calculation for a pixel assigned to the class 'low elevation' with a 'shallow soil' would thus be calculated by:

$(avPV_{ShS} + avPV_{LE}) / 2$
i.e. (11+14.7)/2 = 12.85

In case of different weights (W_{Parx}) for the different influencing parameters (soil, elevation), Equation 7 applies. Note that the weights have to be between 0 and 1 and have to sum up to 1.

$$avPV_{cropi} = \sum(avPV_{Parx} * W_{Parx} * No_{inPar}) / No_{inPar}$$

where
$avPV_{cropi}$= average production value per pixel per crop i
$avPV_{Parx}$ = average production value per pixel per crop i in parameter x
W_{Parx} = Weight of parameter x
No_{inPar} = Number of input parameters

Equation 7: Production value per pixel of crop i

Example:
Under the assumption, that the soil influence is 30% and the elevation influence is 70%, a pixel in the 'low elevation' class with a shallow soil would be calculated by:

No_{inPar} = 2 (soil, elevation), W_{soil} = 0.3, $W_{elevation}$ = 0.7

$(avPV_{ShS} * W_{soil} * No_{inPar} + avPV_{LE} * W_{elevation} * No_{inPar}) / No_{inPar}$
(11* 0.3 * 2 + 14.7 * 0.7 * 2) / 2 = 14.91

9. The '**product-to-residue-ratio'** for most crops has a high spatial variability and thus should be set by a local expert. If no expert information is available averaged values from literature can be used as well.
10. Based on the 'product-to-residue-ratio' for crop i, the **amount of residues** per pixel can be calculated.
11. Using **local expert conversion factors**, the energy content of the calculated agricultural residues of crop i per pixel is calculated.
12. Steps 1-11 are repeated for each crop type grown in the region in order to have a complete estimate of primary residues and their energy values.
13. For each pixel defined as 'arable land' a **total energy value** for primary residues is calculated by adding all energy values for this pixel from each specific crop calculation (step 12). → **Product AM1**

14. Steps 14-17 consist of calculating the additional secondary residues resulting from ‘arable land’ crops in region x for crops i and integrating them in the overall biomass energy calculation. The amount of secondary residues from industries is provided by national statistics or from local experts.
15. The **energy content** of each secondary residue at the administrative level x needs to be calculated based on local expert knowledge. See *Annex 5: Determination of the energy content of biomass*.
16. Sum up the energy content from all secondary residues at the administrative level x.
17. The **total amount of biomass energy** from all crop residues (primary and secondary) contained in class ‘arable land’ is calculated by adding the sum of all pixel-based energy values from the primary residue map and the plot-based total biomass energy value from secondary residues.

5.3.1. Permanent crop residues

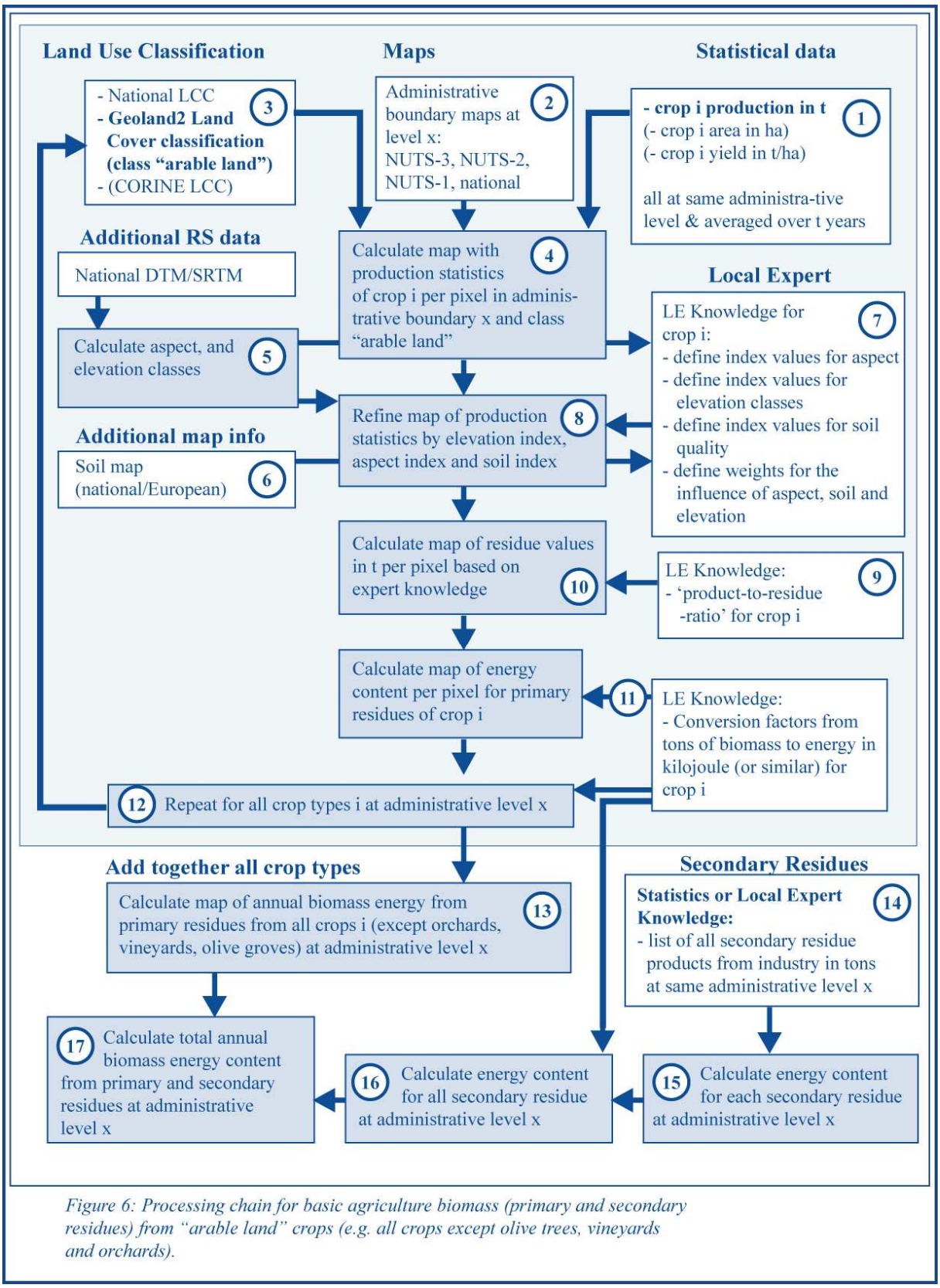


Figure 6: Processing chain for basic agriculture biomass (primary and secondary residues) from "arable land" crops (e.g. all crops except olive trees, vineyards and orchards).

Workflow for residues and biomass energy from 'permanent crops':

1) Check the availability of agricultural statistical data for the required crops and at the highest level of spatial (administrative) resolution. The highest existing resolution should always be preferred. The hierarchy is as follows: NUTS-3 -> NUTS-2 -> NUTS-1 -> national data. The data should all be at the same administrative level for each crop type. If the assessment is only carried out every few years, it is recommended to use average values for the selected time-period. The most important statistical information for permanent crops is "area" per crop type.
2) Depending on the spatial level chosen for the agricultural statistics, download the required NUTS boundary maps (shapefile) from http://cidportal.jrc.ec.europa.eu/thematic-portals/agri4cast/
3) Choose the land cover classification which best suits the agricultural classes from the statistics and which has the highest spatial resolution and is most up-to-date. In many cases this will be the national LCC or the CORINE LCC.
4) Local Expert Knowledge: Since most primary residues (stems, branches, twigs, leaves) with biomass relevance from orchards, vineyards and olive trees are not harvest related, but rather dependent on the number of trees, the production statistics (of orchards) have a limited relevance for biomass assessments from permanent crops. Since statistical data on the number of plants per hectare is not available at EUROSTAT or national level, it is necessary to involve local experts in the assessment of plant density per hectare. The plant density combined with knowledge on the amount of residues per plant will give an average amount of residues per hectare. Data on the amount of residues per tree per crop type can be found in the literature or values have to be defined by a local expert. By multiplying the area (in hectares) of crop i with the average amount of primary residues per hectare of crop i, we obtain a total amount of primary residues of crop i within the administrative boundary x.

   The workflow of step 4 can be summarized by the following formula:

$$TPRV_{pcrop\ i}\ (region\ x) = PS_{pcrop\ i}\ (region\ x) * ERV_{pcrop\ i}\ (region\ x)$$

where

$TPRV_{pcrop\ i}$ (region x) = Total primary residue value of "pcrop i" in tons in region x
$PS_{pcrop\ i}$ (region x) = Area (land use) statistic of "pcrop i" in region x
$ERV_{pcrop\ i}$ (region x) = Estimated residue value of crop i per hectare in region x

Equation 8: Calculation of PPV for each crop and each pixel

5) We now integrate the data from 1), 2), 3) and 4) in a GIS to create a primary residue value (PRV) in tons of residue per crop i for each pixel defined as class 'permanent crop'. This means: Each pixel defined as 'permanent crops' is attributed a region specific averaged residue biomass value from ALL permanent crops (e.g. olives trees, vineyards, orchards) cultivated in the region. Example: A vineyard defined as 'permanent crop' will also be attributed a biomass value for olives and orchards if these exist at the same administrative level. The basic approach without a land cover classification distinguishing between the different permanent crop types cannot attribute the residues for vineyards and orchards accordingly. If national LCCs with higher thematic resolution are used, this problem can be overcome. Many spatial data bases on national or regional scale exist for olive groves and vineyards (e.g. OLIAREA, for details see advanced approach).

In step 4) the total primary residue value (TPRV) for each crop type is calculated. The total amount per crop type is now equally distributed among all pixels defined as 'permanent crops'. By doing this, a pixel-based residue value will be obtained. This is done separately for each crop type.

The workflow of step 5 can be summarized by the following formula:

$$PPRV_{pcrop\ i}\ (region\ x) = TPRV_{pcrop\ i}\ (region\ x) / TNP_{pcrop}\ (region\ x)$$

where

$PPRV_{pcrop\ i}$ (region x) = Pixel-based primary residue value of "pcrop i" (permanent crop i) in tons in region x
$TPRV_{pcrop\ i}$ (region x) = Total primary residue value of "pcrop i" in tons in region x
TNP_{pcrop} (region x) = total number of pixels defined as class "permanent crops" in GEOLAND LCC

Equation 9: Calculation of PPV for each crop and each pixel

6) From **DTM**, elevation classes and aspect maps (see Annex 6: Calculation of Slope and Aspect) can be derived, which are later used as input to set boundary conditions (threshold) by local experts.

7) National or European **soil maps** can be integrated, which are later used as input to set boundary conditions.

8) Based on **local expert knowledge** several indexes (ranging form 0.0 (not suitable) to 1.0 (ideal)) are produced determining growing conditions depending on a) elevation criteria; b) aspect criteria; c) soil criteria. The soil index should follow the same classes used in the soil map.
The local expert has to define weights for each of the three parameters soil, aspect and elevation. These weights reflect the influence of each parameter on the crop growth. The integration of other parameters, such as pruning methods, can be integrated in the same way. The values have to be between 0 and 1 and have to sum up to exactly 1.

9) The results of step 5 – the pixel based residue values – are now refined with the local expert defined indexes and weights. Each pixel is multiplied with an index value based multiplication factor, in such a way, that the overall agricultural statistics values do not change. An example of how to use a soil and elevation index is given below.

   Example: Calculation of refined residue value per pixel and crop (PPRVcrop i) with boundary condition indexes (soil and elevation):

   Red: Input from statistics (TERV = Total Estimated Residue Value. E.g. 1000t)
   Turquoise: Inputs from soil map/ elevation classes: Pixels per class
   Dark green: Input from land cover map: Total no. of pixels classified as 'permanent crops'. E.g. = 100 pixels
   Yellow: Local expert knowledge

Table 16: Example calculation of refined production value per pixel and crop using soil boundaries.

Soil	**area (pixels)**	**Index (0 = worst; 1 = best soil)**	**Intermediate result (no unit)**	**MF calculation**	**$avRV_{soil}$ per pixel per class = MF * Index**	**Total RV per class = $avRV_{soil}$ * area**
Permanently wet soils ($_{ws}$)	5 $area_{WS}$	0.2 $index_{WS}$	1 PI_{WS}		4.4 $avRV_{WS}$ = MF * $index_{WS}$	22 RV_{WS} = $avRV_{WS}$ * $area_{WS}$
Sandy soils ($_{SS}$)	10 $area_{SS}$	0.2 $index_{SS}$	2 PI_{SS}		4.4 $avRV_{SS}$ = MF * $index_{SS}$	44 RV_{SS} = $avRV_{SS}$ * $area_{SS}$
Shallow soils ($_{ShS}$)	8 $area_{ShS}$	0.5 $index_{ShS}$	4 PI_{ShS}		11 $avRV_{ShS}$ = MF * $index_{ShS}$	88 RV_{ShS} = $avRV_{ShS}$ * $area_{ShS}$
All other soils ($_{oth}$)	77 $area_{oth}$	0.5 (no info, e.g. assumption = average)	38.5 PI_{oth}		11 $avRV_{oth}$ = MF * $index_{oth}$	847 RV_{oth} = $avPV_{oth}$ * $area_{oth}$
Total	100 total area in pixel of crop i		45.5 Sum of pixels by index (SPI) =∑(PIx)	~ 22 Multiplication factor (MF) = TERV/SPI		1000 TERV (total estimated residue value per crop in tons in region x)

Table 17: Example calculation of refined production value per pixel and crop using elevation boundaries.

Elevation	**area (pixels)**	**Index (0 = worst; 1 = best soil)**	**Intermediate result (no unit)**	**MF calculation**	**$avRV_{elevation}$ per pixel per class = MF * Index**	**Total RV per class = $avRV_{elevation}$ * area**
High elevation ($_{HE}$)	40 $area_{HE}$	0.2 $index_{HE}$	8 PI_{HE}		2.94 $avRV_{HE}$ = MF * $index_{HE}$	22 RV_{WS} = $avRV_{WS}$ * $area_{WS}$
Low elevation ($_{LE}$)	60 $area_{LE}$	1 $index_{LE}$	60 PI_{LE}		14.7 $avRV_{LE}$ = MF * $index_{LE}$	44 RV_{SS} = $avRV_{SS}$ * $area_{SS}$
Total	100 total area in pixel of crop i		68 Sum of pixels by index (SPI) =∑(SPIx)	~ 14.7 Multiplication factor (MF) = TERV/SPI		1000 TERV (total estimated residue value per crop in tons in region x)

Under the assumption that both factors (soil and elevation) influence the TPV to the same extent (0.5/0.5), the calculation for each pixel is done by:

$(avPV_{soil} + avPV_{elevation}) / 2$

The value calculation for a pixel assigned to the class 'low elevation' with a 'shallow soil' would thus be calculated by:

$(avPV_{ShS} + avPV_{LE}) / 2$
i.e. (11+14.7)/2 = 12.85

In case of different weights (W_{Parx}) for the different influencing parameters (soil, elevation), Equation 12 applies. Note that the weights have to be between 0 and 1 and have to sum up to 1.

$$\mathbf{avPV_{cropi} = \sum(avPV_{Parx} * W_{Parx} * No_{inPar}) / No_{inPar}}$$

where
$avPV_{cropi}$= average production value per pixel per crop i
$avPV_{Parx}$ = average production value per pixel per crop i in parameter x
W_{Parx} = Weight of parameter x
No_{inPar} = Number of input parameters

Equation 10: Production value per pixel of crop i

Example:
Under the assumption, that the soil influence is 30% and the elevation influence is 70%, a pixel attributed to the 'low elevation' class and the 'shallow soil' class would be calculated by:

No_{inPar} = 2 (soil, elevation), W_{soil} = 0.3, $W_{elevation}$ = 0.7

$(avPV_{ShS} * W_{soil} * No_{inPar} + avPV_{LE} * W_{elevation} * No_{inPar}) / No_{inPar}$
(11* 0.3 * 2 + 14.7 * 0.7 * 2) / 2 = 14.91

10) Definition of energy conversion values for permanent crop primary residues by local experts or scientific literature (see also Annex 5: Determination of the energy content of biomass).
11) Based on the **local expert** or literature information on energy conversion values we can now calculate the amount of energy from permanent crop residues of crop i per pixel.
12) Steps 1-11 are repeated for each permanent crop type grown in region x in order to have a complete estimate of primary residues and their energy values. For each pixel defined as 'permanent crops' a total energy value for primary residues is calculated by adding all energy values for this pixel from each specific crop type calculation.
13) Steps 13-16 consist of calculating the additional secondary residues from permanent crops in region x for all crops i and integrating them in the overall biomass energy calculation. The amount of secondary residues from industries will have to be provided by national statistics or from local experts.
14) The **amount of energy** derived from each secondary residue at the administrative level x needs to be calculated based on local expert knowledge or averaged values from literature. For conversion values and methodology see *'Annex 5: Determination of the energy content of biomass.'*
15) The **total amount of biomass energy at the administrative level** x is calculated by summing up all energy values for the secondary residues of each crop i from step 15.
16) The **total amount of biomass energy in region** x from all permanent crop residues (primary and secondary) contained in the class 'permanent crops' is finally calculated by

adding the sum of all pixel-based energy values from the primary residue map and the plot-based total biomass energy value from secondary industrial residue products.

5.3.2. Biomass from grasslands

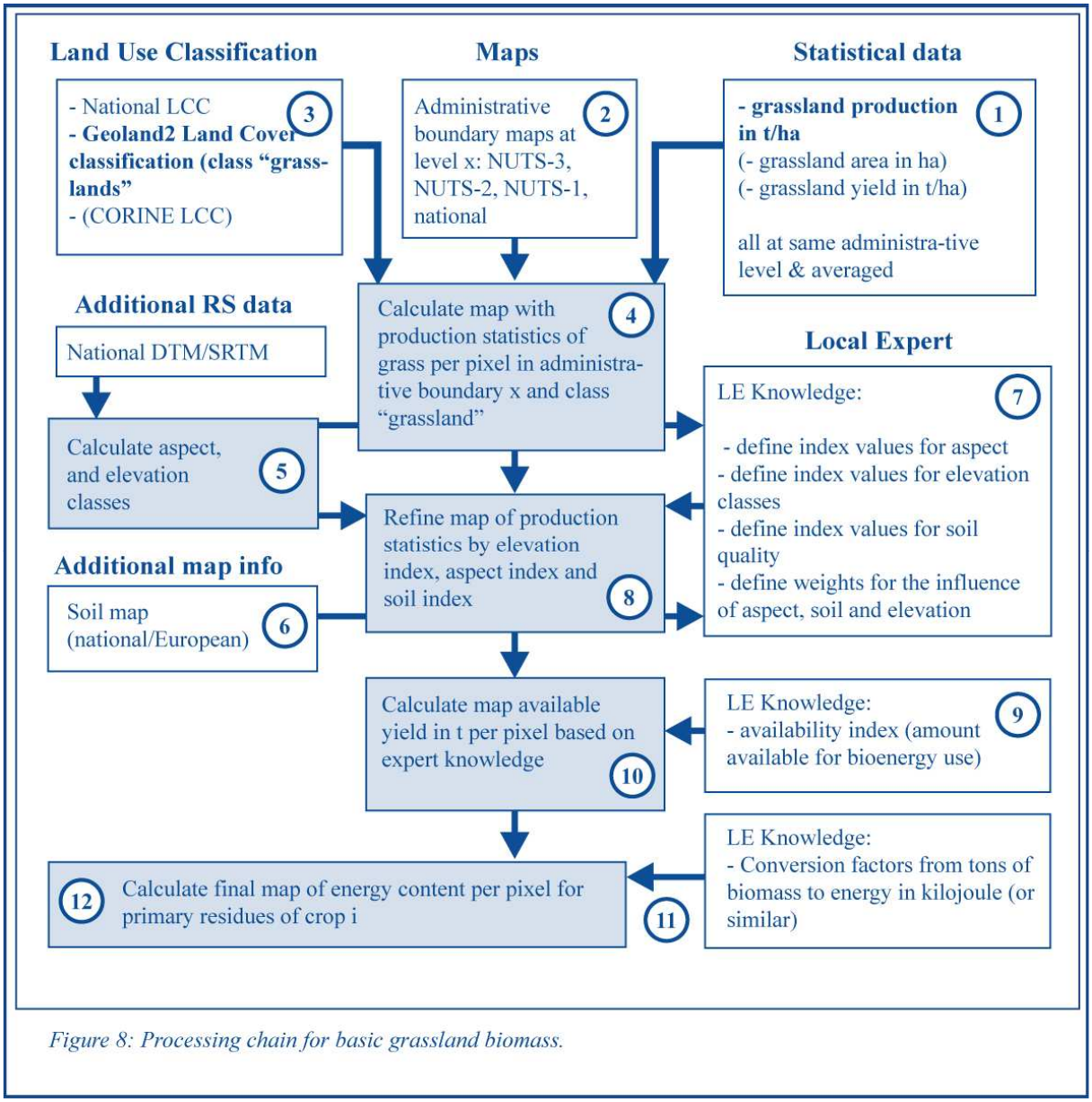


Figure 8: Processing chain for basic grassland biomass.

Processing chain:

The processing chain for grasslands is identical to the first 11 steps as outlined in chapter 0 on annual crop residues. There are a number of differences in the input data and the expert knowledge required though. Instead of repeating the entire processing chain for grasslands, we refer to chapter 0 and focus on the differences between the two processing chains here:

- Step 1: Input data is the grassland statistics available through EUROSTAT. It is necessary to add together both the production values in tons per ha for temporary and for permanent grasslands.
- Step 2: EUROSTAT data for grassland production is available at national level only. If data at higher spatial resolution is available through national data centers then NUTS boundary maps will have to be included.
- Step 3: From the GEOLAND2 LC classification the class 'grasslands' can be used as RS classification input. If the GEOLAND2 consortium implements a higher thematic resolution in their final grassland layer, - see description above - a further differentiation of grassland types is feasible, as long as these classes are congruent with the EUROSTAT grasslands statistics. In case they are not congruent, transfer functions can be set up, but this would need some more detailed investigations on the relation between temporal/permanent and intensive/extensive grasslands and their respective yields.
- Steps 4-8 are identical to the annual crop residue processing.
- Step 9: Instead of the 'product-to-residue ratio' needed for the assessment of crop residue biomass, we need to know the amount of grass that is not used for livestock feeding or other purposes and which can be used for bio energy purposes. While it is agreed among the scientific community that grasslands provide a valuable source of bio energy, there are still many discussions concerning the available energy from grassland biomass and it has been shown that energy values and the available production of grass for energy purposes vary considerably at each specific site (Tilmann et al., 2009; Rösch et al, 2009). Further research is still needed to solve these issues. In order to account for these site specific variations it is currently necessary to rely on local experts to define the amount of grass available for energy purposes (index value).
- Step10: identical to 'annual crop residues' process
- Step 11: the conversion factor for grassland biomass to grassland bio energy is largely based on water content, grass type and growing conditions. These are site specific values and are best assessed by local experts. Generalized values can also be found in the scientific literature, e.g. http://www.vt.tuwien.ac.at/Biobib/biobib.html

5.4. Energy crops biomass

Certain tree species and agricultural crops have the potential to produce large amounts of biomass per unit of area occupied. These vegetation types are of particular interest for systematic fuel production. The typical energy crops can be divided into five groups: **woody plants**, **starch crops**, **oil seeds**, **sugar crops** and **grasses**. However, the products of some of these vegetation types also can be used as food or industrial feedstock. Therefore a competition between food and biomass use is to be expected in some cases. For example, agricultural crops are primarily grown for food or animal feeding, grasslands are often used for grazing and woody forest biomass is used by the lumber industry. This section will focus on vegetation types providing a high energy yield, but without a currently competitive use beside biomass production for energy, which are today mainly SRC and energy grasses.

Starch crops, sugar crops and oil seeds are not energy crops per se, but used mainly for other purposes (food, fodder). Only within the last decades, the use of such crops for energy purposes is increasing. New species, such as the Triticale species (*Tritosecale sp.*) became more important. Triticale is a man-made hybrid species, resulting from the crossing of wheat (*Triticum sp.*) and rye (*Secale sp.*). The species was the result of efforts to imbue the wheat crop with the resistances of rye to environmental stress factors and diseases. Originally it was aimed for food production, however it also saw use as animal feed and is nowadays used as an energy crop. Especially for oilseeds, the use for energy purposes is not congruent with the defined frame conditions as Europe is importing large amounts of oil and fat for food. This situation can of course change in future. Within the CEUBIOM basic approach, these crops can only be treated statistically due to the usage problem given above.

The following sections give a short overview on SRC and energy grasses, as those are the ones with currently the least competitive use, followed by a proposal for a basic statistical approach. The reason for not integrating remote sensing in this approach here is the lack of operational or at least well tested tools and the problem of usage. The problem of usage occurs, as it is not possible to assess from remote sensing, whether a crop is used as energy crop or whether is used for food or feeding. For spatially explicit methods using remote sensing technology, the reader is referred to the advanced approach on energy crops, where some fairly well developed approaches for Triticale, Miscanthus and SRC are given, although the usage issue still remains unsolved.

5.4.1. Woody energy crops: Short rotation coppice (SRC)

Short rotation coppice (SRC) is an adjusted method of managing woodland consisting of vegetation types with high energy-yielding biomass. The most common species used in such systems are Willow (*Salix sp.*) and Poplar (*Populus sp.*) varieties. Willow is densely planted with 15,000 plants per hectare, while Poplar more sparsely at 10,000 – 12,000 plants per hectare. Harvesting of the woody biomass takes place in more frequent intervals for Willow, between 1 and 5 years usually, as opposed to 3-5 years for Poplar. The initial establishing period for both vegetation types is about 4-5 years. After harvesting, they regenerate from the stools, which are expected to survive 5 rotations at least. Yield is quite variable and it depends on plant genotype and environmental conditions, but and average production is about 4.9 to 10.7 over-dry tonnes per hectare per year (Aylott et. al., 2008).

The development of SRC for renewable energy production is a new sector with potential for considerable expansion, offering benefits for growers, developers, consumers, local

communities and the environment. Planting in twin rows allows harvesting of two rows at a time, usually using direct cut and chip methods. Research is continuing into the optimum spacing between varieties. It is one of the factors, together with better pest management, which may lead to increased productivity. Converting existing arable land to SRC will reduce the amount of agricultural chemicals required as SRC is a low input crop: once established it requires a very much lower input of chemicals than conventional arable crops.

Table 18: Typical data on short rotation coppice in Europe

Species	Willow	Poplar	Robinia
Part of Europe	Scandinavia, British Islands	Central Europe	Mediterranean Europe
Crop density stools/ha	18-25,000	10-15,000	8-12,000
Rotation years	3-4	1-3	2-4
Av. butt diameter at harvest (mm)	15-30	20-50	20-40
Av height at harvest (m)	3.5-5.0	2.5-7.5	2.0-5.0
Growing stock at harvest (fresh tons/ha)	30-60	20-45	15-40
Moisture content (% weight)	50-55	50-55	40-45

The system used to harvest, store and transport the SRC crop depends on the scale of the operation, the specification of the end user and a host of local factors such as access and road size. SRC is usually harvested after two to five years of growth. The average harvesting of SRC, using a chipper or mechanical harvester, is around three hectares a day, depending on the type of harvester used and the size and layout of the plantation. With this in mind, it might be possible to have three different age-classes of SRC in one 10-hectare field.
There are two main systems for harvesting SRC:

- Direct cut systems are based on principles used for other agricultural crops, where the whole crop is cut and chipped or billeted in one operation. This system is most likely to be operated by contractors or grower co-operatives because of the initial high investment in machinery. Less expensive tractor mounted versions are also available and may be feasible for smaller operations.
- Stick harvesting systems involve a number of operations before the chips are available for use. Sticks are cut with one pass of either a self-propelled or trailed machine, which are less expensive than cut and chip harvesters. The sticks are then laid on the headland. From here they are loaded onto a tractor with suitable attachments and transported to the farm storage area, where they are stacked and stored.

5.4.2. Energy grasses

Perennial grasses are widely used as fodder crops and have in former times significantly contributed to the energy supply on farms. Since the mid-1980s there has been increasing interest in the use of specific perennial grasses as energy crops through a number of modern energy conversion routes.
The characteristics which make perennial rhizomatous grasses (PRG) attractive for biomass production are their high yield potentials, the high lignin and cellulose contents of their biomass and their generally anticipated positive environmental impact. Because the need for soil tillage in perennial grasses is limited to the year in which the crops are established the risk

of soil erosion is significantly lower than in annual crops and soil carbon contents increase. The rhizome system of perennial rhizomatous grasses allows them to recycle and store nutrients. This results in very efficient use of nutrients and low demand for fertilizers. Since few natural pests occur they may also be produced with little or no pesticide use. Studies on flora and fauna showed that perennial rhizomatous grasses increase the abundance and activity of different species, especially birds, mammals and insects. Perennial rhizomatous grasses can therefore contribute to the ecological value of agriculture and function as landscape elements.

Table 19: An overview on perennial grasses tested as energy crops in Europe and the reported yields.

Common English name	**Latin name**	**Photosynthetic pathway**	**Yields reported [t dry matter/ha/year]**
Miscanthus	*Miscanthus spp.*	C4	5 - 44
Switchgrass	*Panicum virgatum L.*	C4	5 - 24
Giant Reed	*Arundo donax L.*	C3	3 - 37
Reed canarygrass	*Phalaris arundinacea L.*	C3	7 - 13
Meadow Foxtail	*Alopecurus pratensis L.*	C3	6 – 13
Big Bluestem	*Andropogon gerardii Vitman*	C4	8 - 15
Cypergras, Galingale	*Cyperus longus L.*	C4	4 - 19
Cocksfoot grass	*Dactylis glomerata L.*	C3	8 - 10
Tall Fescue	*Festuca arundinacea Schreb.*	C3	8 - 14
Raygras	*Lolium ssp.*	C3	9 - 12
Napier Grass	*Pennisetum purpureum Schum*	C4	27
Timothy	*Phleum pratense L.*	C3	9 – 18
Common Reed	*Phragmites communis Trin.*	C3	9 - 13
Sugar cane	*Saccharum officinarum L.*	C4	27
Giant Cordgrass/	*Spartina cynosuroides L.*	C4	5- 20
Prairie Cordgrass	*Spartina pectinata Bosc.*	C4	4 - 18

Source: Lewandowski et al., 2002

The choice of the appropriate location is the most important factor driving the biomass yields of the grasses. Miscanthus (Miscanthus spp.), switchgrass (Panicum virgatum), reed canarygrass (Phalaris arundinacea) and giant reed (Arundo donax) are particularly interesting for the following reasons:

- their high biomass yield potential
- the concentration of the yield in one harvest, and delayed harvest is possible
- their persistence and yield stability
- their efficient use of resources and low input demand
- the benefits of their rhizome systems.

Many of the tested C3 grasses shown in the table above have a high potential, but high yields are only obtained with multiple cutting systems and high nitrogen input. A delayed harvest of these grasses is not possible due to lodging. The four grasses mentioned above are characterized by concentrating the yield in one harvest. Furthermore a late harvest, i.e. after winter in early spring, can be performed. A late harvest is the most important mean to optimize the combustion quality of biomass from these grasses because over winter the

biomass can dry out to water contents of 20 % and a significant reduction of combustion relevant components like chloride, potassium, nitrogen and others occurs.

Switchgrass is native to North America where it occurs naturally from 55°N latitude to central Mexico. It is a tall C4 grass. It does well on a wide range of soil types and is drought tolerant.

Table 20: Switchgrass yields by region

Country	dry matter yield [t/ha/year]
The Netherlands	4 - 9
U.K.	5 - 12
Italy	5 - 22
Greece	15 - 24

Miscanthus is a perennial grass, originally an ornamental plant in Japan and arrived in Europe in the early 1930s. Due to its C4 photosynthetic pathway it has a high yield potential for cellulose and fibre, which was investigated in the 1960s. Trials on its potential for the production of bioenergy began in the 1980s (Scurlock, 1998). Energy production is achieved either through combustion or anaerobic digestion. The crop requires a year to be established and from the second year onwards can be harvested annually, remaining viable for up to 15-20 years. The species most commonly used is *M. x gigantheus*, a sterile hybrid produced by crossing *M. sinensis* and *M. sacchariflorous*, which can reach up to 4 metres height (Zub and Brancourt-Hulmel, 2009).

Table 21: Miscanthus yields by region

Country	dry matter yield [t/ha/year]
Denmark	5- 15
Germany	4- 30
U.K.	10 - 15
Switzerland	13 - 19
Austria	22
Spain	14 - 34
Greece	26 - 44
Italy	30 – 32

Reed canarygrass is a C3 grass which is native in the temperate regions of Europe. It is naturally found in wet areas and in some world regions still used as fodder crop. Reed canary grass grows on most kind of soils and is one of the best grass species for poorly drained soils because it tolerates flooding. Reed canary grass is adapted to and grows very well in a cool climate. It has good winter hardiness and survives well in north Scandinavia. Dry matter yields typically reported for Scandinavian countries are 6 – 12 t DM/ha/year.

Giant reed is thought to be originated from Asia but is also considered as a native species to the countries surrounding the Mediterranean Sea. Giant reed is a very tall growing C3 grass. It tolerates a wide range of ecological conditions and is a species adapted to warm temperate or subtropical regions.

Table 22: Giant Reed yields by region

Country	dry matter yield [t/ha/year]
South Greece	7– 31
North Greece	5– 17
Spain	8– 37
South Italy	15 – 34
North Italy	3– 32
Germany	15 – 20

One of the main barriers for the production of perennial rhizomatous grasses for bioenergy is the high biomass production costs. These can in future be reduced by:

- The development of more cost effective and safe establishment methods
- Mechanisation of establishment and harvest of PRG
- Breeding of varieties for biomass production and adapted to all areas of Europe, especially dry areas
- Further development of the crop management system for PRG
- Biomass quality management
- Quantification of ecological benefits, integration into multiple land use systems.

5.4.3. Proposed approach for energy crops assessment

Until now there are no energy crop statistics available (or they are very poor), but so far the area covered by energy crops is still very small. Taking into account this information, it is time to start collecting energy crop statistics uniformly within the EU and even better throughout Europe.
Official statistics should have, at least, the following data on energy crops which are summarized in Table 23. These data should be assessed at least on national level spatially and on an annual base temporally to be able to report these data to EUROSTAT. Of course, statistics offices in a country could have data by from regions within a country. In addition to the statistical information and due to the small extent and thus small effort, additional spatial information should also be given (which parcels are concerned). Based on these two sources, it is possible to calculate a map of biomass for energy from energy crops using the same methodology as for agricultural crops. The main difference is that instead of only using residues the whole crop is used (and thus calculated). For a detailed classification of energy crops from remote sensing, the reader is referred to the advanced approach.

Table 23: Proposal for energy crop statistics

Crop type/Crop group	Total area sown (ha) in year X	Area harvested (ha) in year X	Yield (dry matter t) in year X
SRC			
willow			
poplar			
robinia			
Other SRC			
Oilseeds for bio-energy only			
Rapeseed			
Sunflower			
Soybean			
Other oilseeds for bio-energy only			
Sugar crops for bio-energy only			
sugar cane			
sweet sorghum			
Other sugar crops			
Starch crops for bio-energy only			
maize			
triticale			
Other starch crops			
Energy grasses			
miscanthus			
switch grass			
reed canary grass			
giant reed			
other energy grasses			

6. Advanced approach

The advanced approaches include more detailed data and more sophisticated methods from the remote sensing side than the basic approach. Furthermore, the results will be different, since more detailed data and methods will lead to more accurate results.

6.1. Input data

The input data for the advanced approaches for the different biomass types are much more heterogeneous than for the basic approach. Thus it is not useful to give a complete list on input data at this point. Instead, the needed data (both terrestrial/statistical and remote sensing data) is given for each approach individually in the respective sections. Generally, the statistical/terrestrial data sources are mostly the same as for the basic approach, while the EO data vary more significantly.

6.2. Advanced approach for forestry biomass

There are several methods and options currently available for the assessment of forestry biomass from remote sensing data. It is difficult to compare them, because they generally cover different areas, forest types and may be done for different purposes (forest management vs. biomass potential assessments). One already successfully implemented system is the use of kNN methodology to combine medium resolution optical data with NFI plots for the estimation of biomass in Europe [Gallaun et al., 2010.]. This is a very good product for a top-down overview on above-ground biomass, however, it does not meet the spatial resolution requirements requested by our end users. Thus, two alternative approaches are described in this section: an indirect approach based on LiDAR data and one direct approach based on SAR data.

6.2.1. Advanced approach using LiDAR data

Very accurate results for estimating biomass can be obtained by using tree species, stem number and diameter at breast height (DBH). However, DBH can only be measured in the field, which is for large areas very time consuming and costly. Instead of DBH, tree height can be measured more efficiently by remote sensing. Thus as already mentioned in D4.2, the key parameters to estimate forest biomass from remote sensing are the following:

- forest area
- tree species (-mixture)
- tree density (crown cover or stem density depending on the data source)
- tree height

Forest area, tree species and crown cover as a density parameter are foreseen to be available through the GMES core service products for land (see GEOLAND 2 project: [GEOLAND2, 2009]). In order to generate tree height, a DTM (digital terrain model) and a DSM (digital surface model, i.e. the height of the canopy) are needed.

DTMs are available from many sources, as already given above. These DTMs are perfectly suitable to generate aspect, slope or elevation classes etc; and they are also quite accurate in terms of absolute height outside forest. In forest areas however, these models show severe errors in height. Investigations in Austria showed errors of up to 10 m beneath forest and this

is expected to be similar in other countries. Such errors in DTM would lead to similar errors in the estimation of the tree height. The only option to derive a high quality digital terrain model (DTM) beneath forest over large areas currently is by using LiDAR technology.

While there are several options to generate a DSM (LiDAR, photogrammetry and interferometric SAR processing (InSAR)) LiDAR is the most accurate remote sensing source for generating a DTM. Both are needed for an accurate estimation of tree heights. Thus currently LiDAR is the best option to derive tree heights, but unfortunately at very high costs. However, LiDAR data is currently used for national or sub-national assessments of forest resources and biomass (digital surface model DSM in combination with the DTM) in many European countries. Thus existing LiDAR data sets (both DTM and DSM) should be used wherever available. For future updates, generally only the DSM has to be updated, because the terrain (DTM) does not change significantly over time in most cases. Since LiDAR acquisitions are expensive and time consuming, alternative systems might be more suitable for updating the DSMs. For a homogeneous DSM update of the whole of Europe, satellite image photogrammetry would be a much more economic alternative, which could be developed to an operational use for such large area.

It has to be mentioned, that due to the high costs, a flight campaign for a LiDAR based advanced approach would probably never be done for a biomass study alone. Therefore, the use of other remote sensing methods to obtain forest parameters as an intermediate result on the way to a direct biomass potential assessment, would be beneficial to a number of users, such as forest management services and administrations, national forest services, national parks, managers of protection forests, forest industry, forest owner associations, etc. These organizations could use this forest parameter information to encourage e forest owners to do the necessary management measures. This could increase the amount of biomass available for energy on the market.

Airborne LiDAR (Light Detection and Ranging) is an active remote sensing technology emitting laser pulses in the visible or near infrared wavelength and measuring the time lag between the emission and the return of the reflected pulse(s). If a laser pulse is send out over a vegetated surface such as forest, multiple reflections can occur. Typically the first reflection (first pulse) represents the height of the canopy, while part of the beam penetrates the canopy and is reflected as a last pulse from the ground. Filtering techniques are used to separate ground and canopy signals [Wack and Wimmer, 2002]. This kind of data has proven to be very useful to derive main forest attributes, as a large amount of scientific papers have been dealing with this issue over the past decade. Some early works were done in the frame of the HIGHSCAN project [Hyyppä and Hyyppä, 1999, Hyyppä et al., 2000, Hyyppä et al., 2002, Ziegler et al., 2002]. There are basically two different ways of deriving forest parameters using first and last pulse data: either on an individual tree basis [Koch et al., 2006, Pitkänen et al., 2004] or on stand level [Andersen et al., 2003, Barbati et al., 2009, Koch et al., 2009, Næsset, 2002, Wack and Stelzl, 2005]. For individual tree measurements, the most frequently derived forest attributes are tree position, height, crown width, crown base height and as secondary products diameter at breast height (dbh), basal area and timber volume of the individual trees. Few studies have been trying to extract species information, e.g. [Donoghue et al., 2007]. Stand-level forest attributes are often timber volume or above-ground biomass [Barbati et al., 2009, Hollaus et al., 2009].
A combined single-tree and stand-wise approach is suggested to derive the following forest parameters at a stand level: age class, species mixture, crown cover percentage, dominant tree height, standing timber volume and total above ground biomass. In this regard, the individual tree detection process is only an intermediate result for the derivation of the stand-wise

attributes. The aim of this development was to generate a practical and operational approach of the use of airborne LiDAR data in combination with multispectral satellite images for a large area forest mapping. The idea behind this development was to significantly reduce the amount of both field work and manual digitizing work and thus to reduce costs for the forest inventory. This or a similar approach has been used for forest inventories in Austria, Switzerland, Germany, Norway and Finland.
Based on the total biomass, the amount available per year for energy purposes can again be calculated by following the processing chain of the basic approach.

Work flow

Input data
LiDAR data or alternatively a combination of LiDAR DTM and stereo DSM plus image data available already through GMES (e.g. Image 2006 coverage of Europe).

Methods
The overall process is sketched in Figure 9. with the inputs in light gray and the main processing steps in dark gray. The blue parts can be substituted, if core service data (both orthorectified image data and species information) is available. First, the LiDAR DSM and DTM are used to calculate a vegetation height model (VHM). This VHM is used for the tree top detection. In parallel, the orthophotos can be used to identify ground control points (GCPs) in the satellite scene and further to orthorectify the satellite image (only if an orthorectified satellite image, such as from Image 2006 coverage is not available or not sufficiently up-to-date). This orthorectified satellite image and the VHM are used for the segmentation of forest stands. For the classification of the tree species, a standard pixel-based maximum likelihood classification is performed (or the core service product on tree species or the JRC tree species map is used). Finally, all intermediate results (tree tops, forest stands and species information) and auxiliary information on yield are used for the derivation of the stand-wise forest parameters.

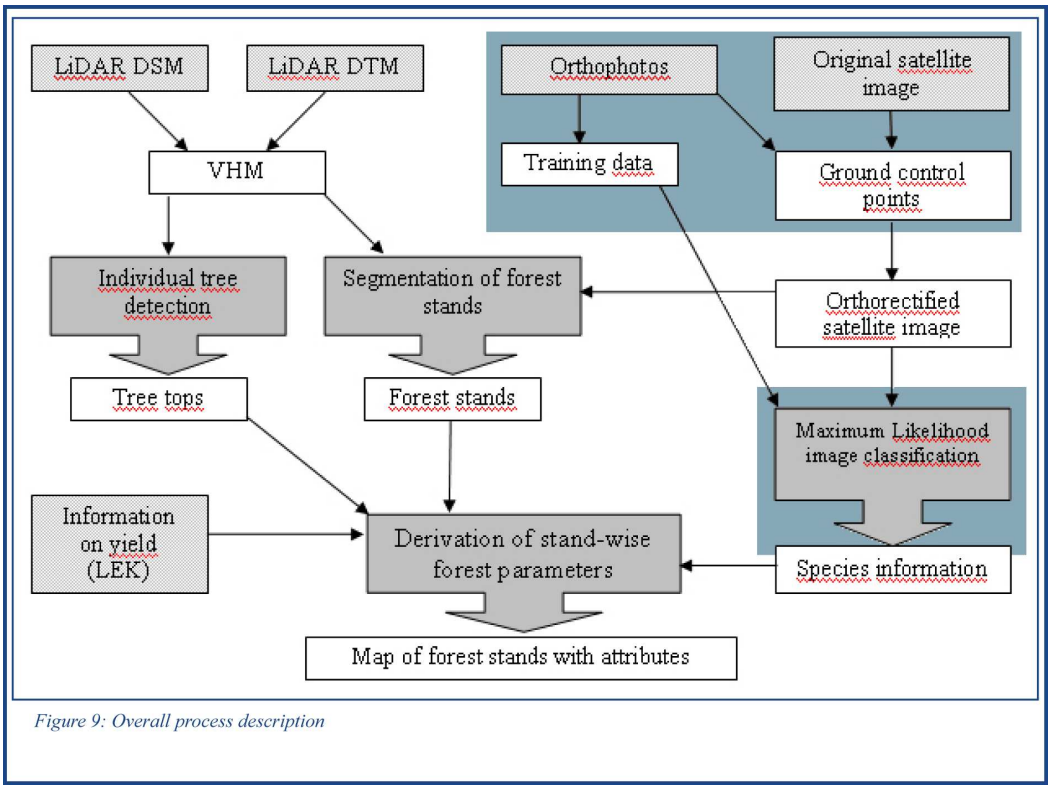


Figure 9: Overall process description

Individual tree detection

The method was developed at the Institute of Digital Image Processing, Joanneum Research [Wack and Stelzl, 2005] and is based on Laplacian-of-Gauss (LoG) filtering. For mathematical details on this filtering approach, see e. g. [Gonzalez and Woods, 2002]. The procedure consists of the following steps; intermediate results are shown in Figure 8.

1. The LoG is used to blur the image, with the degree of blurring being determined by the value of the standard deviation. The procedure used here involves three scales of LoG filtering based on three different sigma values (2, 3, 4) in order to detect trees of different sizes. The results of the LoG filtering with different sigma values are depicted in Figure 8 b, c and d. The dependence of the tree detection success from a single chosen sigma has been discussed [Chen et al., 2006].
2. A local maximum approach is performed on the original VHM, see Figure 8 e.

3. The LoG images are weighted according to their respective level and then added (Figure 8 f).

4. From this summation image, intensity maxima are detected again using LMA; the result is shown in Figure 8 g.

5. Finally, these intensity maxima are dragged to their nearest height maximum (result from step 2). The final result is visualised in Figure 8 h.

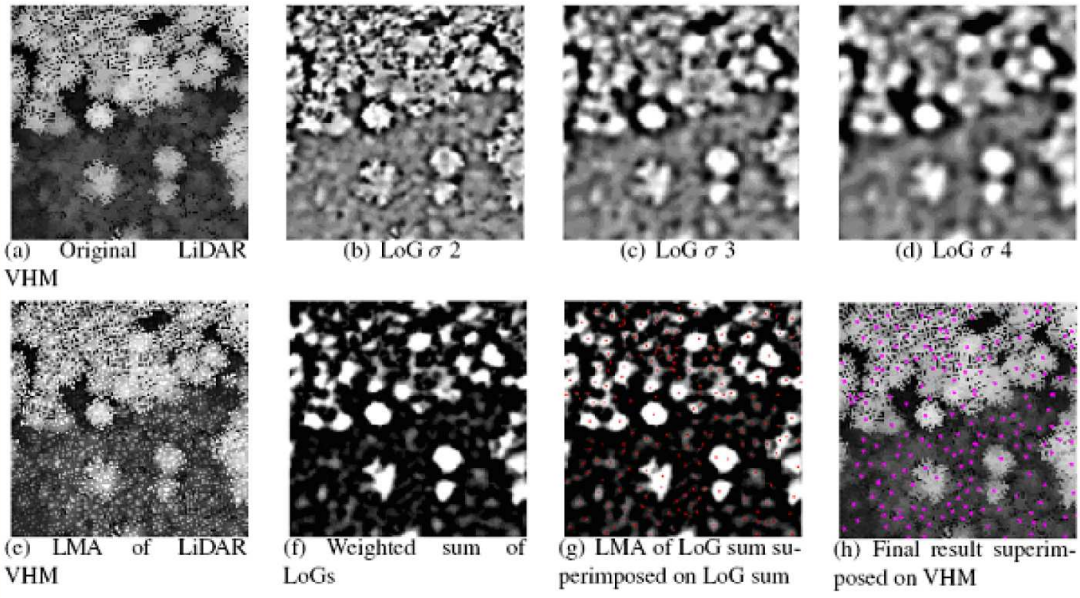


Figure 10: Processing steps and intermediate results for the LoG approach based on LiDAR data (from [Hirschmugl, 2008])

Segmentation of forest stands

A forest stand is typically defined by properties such as age and age distribution, species, density, yield, necessity of measures, site quality etc. These properties are traditionally assessed through field work and through visual interpretation of aerial (stereo) images. In this project, the use of automatic segmentation is assessed in order to save time for manual delineations. A processing chain of several filtering, segmentation and merging steps was set up to generate homogeneous segments. The main input data sets used are again the VHM and the satellite image. In addition, existing information on infrastructure such as roads and forest roads, which are generally considered as fixed stand borders, can optionally also be integrated. It has to be mentioned, that it is not necessary that these segments perfectly mimic

typical traditional forest stand borders, but instead it is vital that segments are homogeneous entities.

Not all properties typically used for forest stand delineation can be derived from remote sensing data; examples are local yield or site conditions. However, some main characteristics can be used:

- the spectral signature of the satellite image has a strong correlation with the tree species (especially the NIR and SWIR bands for coniferous and deciduous differentiation);
- the tree height (VHM) is typically correlated with the age of a stand (with some restrictions);
- tree density and structure are well represented in the LiDAR VHM.

Thus, the first step for a forest stand segmentation is the generation of an artificial stack of three bands consisting of

1) the first principal component image of the multispectral SPOT image
2) the mean height information generated from the LiDAR VHM
3) a structure feature, also calculated from the LiDAR VHM with a so-called 'sector-statistics' approach

All three inputs were resampled to a common resolution of 5m. This three-band image was then integrated with existing forest roads as fixed stand borders and segmented using a region growing approach. In a post-segmentation step, segments below the minimum mapping unit were merged with the adjacent, spectrally most similar segment. The automatically generated segments of the forest stands were finally revised visually where necessary.

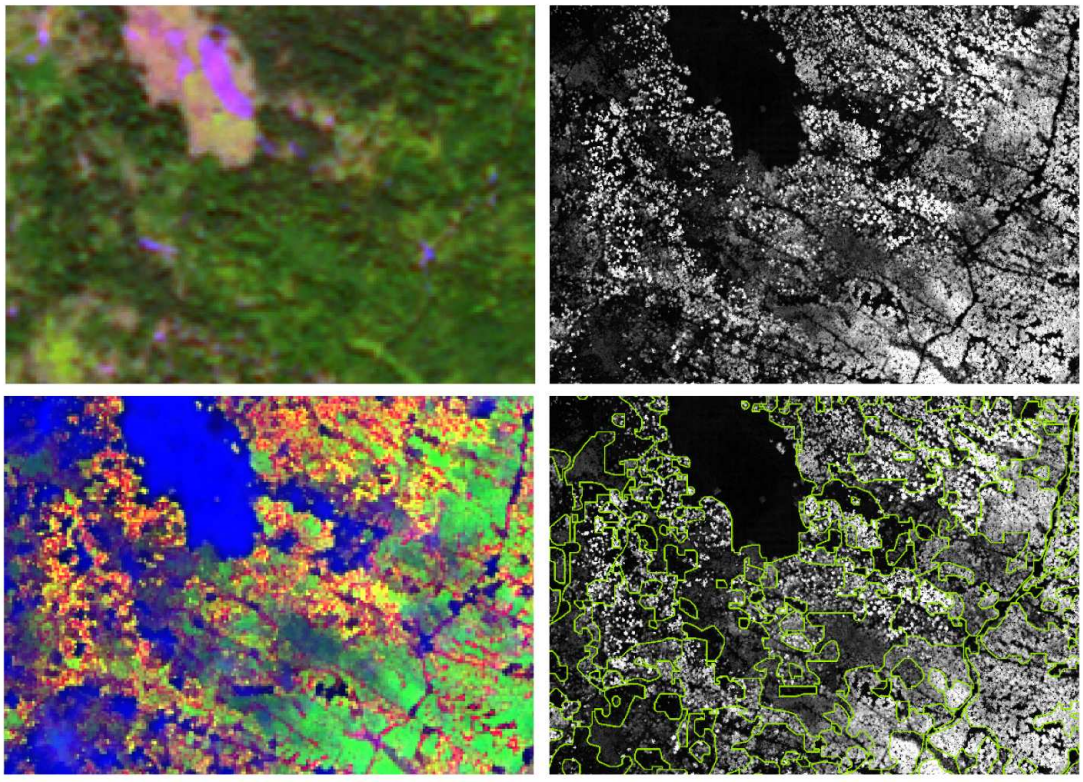


Figure 11: (a) SPOT image; (b) VHM; (c) artificial stack of properties; (d) VHM overlaid with segment borders

Derivation of stand-wise forest parameters

Height information:
Based on the individual tree detections, three different segment-wise height values are estimated: dominant height, mean height and dominant height of the suppressed trees. These three values are calculated as follows:

- Dominant height = Mean height of the 20% highest detected trees of the segment
- Mean height = mean height of all detected trees within the segment
- Dominant height of the suppressed trees = mean height of the 20% highest detected trees smaller than 2/3 of the dominant height.

Crown cover percentages:
For the estimation of the crown cover percentage of each segment, the VHM was cut off at a user-defined threshold (in the current study at 1.3m) and all areas above this threshold are considered as covered. By merging this info with the segmentation, the crown cover percentages can be calculated for each segment.

Stage of stand development:
There is a variety of definitions for the different development stages of forest stands. As an example we here list the definitions according to the yield tables from Badoux [Badoux, 1983] in Table 24.

Table 24: Definitions for stages of stand development

Structure	Stage of development	Crown cover	Diameter of dominant layer (d_{dom})	Dominant height (h_{dom})	Code
homogeneous	Young stands	> 20%		<= 1.3 m	1
	Thicket	> 20%	<12 cm	> 1.3 m -	2
	Pole timber 1	>= 20%	12-20	Relation between h_{dom} - d_{dom} according to yield tables from Badoux	3
	Pole timber 2	>= 20%	21-30		4
	Timber 1	>= 20%	31 -40		5
	Timber 2	>= 20%	41 -50		6
	(Timber 3 - strong timber)	>= 20%	> 50		7
heterogeneous	mixed	>= 20%	mixed	Threshold through standard deviation of height values	8
N/A	Not interpretable		-	-	99

Timber volume and total above-ground biomass:
For the estimation of the timber volume, two options are possible:
1) use the total amount of timber volume from NFI, if this is a trustworthy value and just use the LiDAR data for an accurate distribution on the area or
2) correlate the parameters per segment with local terrestrial timber volume calculations and scale up to a full coverage.

Option 1) would result in the same amount of biomass available as from the statistical assessment, while option 2) would provide different sums.

For detailed description of option 1), the reader is kindly referred to [Wack, 2006]. Based on these parameters different predictive models can be set up and tested with regression analysis

using ground truth data. The parameters were used for the estimation of forest parameters of eucalyptus plantations [Wack et al., 2003] and for mixed forests in Austria [Wack, 2006] with good results.

Based on the forest parameter values, the amount of biomass for energy can be estimated by using conversion values or equations from literature or from local expert knowledge as described in the basic approach.

6.2.2. Advanced approach using SAR data

State of the art in direct biomass assessment from SAR data

Initially, methods of deriving information on vegetation growth conditions and biomass were based on optical data, collected by environmental satellites with sensors of different resolutions (low and high-resolution satellite images) and indirect estimation of biomass. The application of multitemporal SAR data proved to be very useful for classification of vegetation and application for direct biomass assessment.

Depending on the frequency and polarization, waves penetrate into the vegetation. Backscatter and beam penetration will not only vary in dependence on the sensor properties, but also due to different forest canopy, forest composition, density, stems per hectare [Manual of Remote Sensing, 1998].

Generally longer wavelengths (such as L and P) cause stronger penetration into the forest canopy, while shorter wavelengths (like X and K) penetrate less far. The study of backscatter and the interaction of the radar beam with tree crowns and trunks is an important subject for assessing the biomass from radar data. There are different interactions with various tree elements at different wavelength. The recorded signal at different wavelengths contains information on the above ground biomass. The contribution of leaves to radar backscatter is significant at short wavelengths (K; X). At longer wavelengths (L; P) leaves do not contribute to backscatter and attenuate the wave.

a) Vegetation classification

The first step for a biomass assessment is to classify vegetated areas. This part can also be skipped by using up-to-date land cover maps (e.g. from GEOLAND 2 core services or national maps).

b) Biomass Assessment

Radar signals of different frequencies are sensitive to above-ground biomass up to 80-200 tons/ha [Hussin et al, 1991; Dobson et al., 1992; Le Toan et al., 1992; Beaudoin et al 1994. Rauste et al., 1994; Rignot et al., 1994; Ranson et al., 1997].

Due to backscatter saturation the following frequencies are useful for measuring biomass with certain limitations:

- C band may measure forestry biomass up to max. 50 t/ha,
- L band up to approximately 100 t/ha
- lower frequencies such as P-band (68-cm wavelength) up to 200 t/ha [Dobson et al 1992; Le Toan et al 1992; Ulaby et al 1993]
- L band the biomass was saturated [Watanabe et al 2006]
  - above 50 t/ha in σ^0 VV
  - over 100 t/ha in σ^0 HH
  - over 100 t/ha in σ^0 HV when all forest species are included.

  The σ^0 HH for spruce revealed greater saturation levels than for the other forest species.
- P band for HH polarization, the trunk ground backscatter dominates

Biomass assessment using L and P BAND

Table 25 presents adjusted coefficients of determination R^2 between σ^0 and the biophysical parameters and regression coefficients. The correlations were examined using two regression models, logarithmic and third-order polynomial functions and the correlation coefficients and fitting parameters [Watanabe et al 2006].

Table 25: R^2s for different polarizations and equations to calculate biomass and tree height from L band SAR

		$y = a\ln(x) + b$			$y = ax^3 + bx^2 + cx + d$				
		a	b	R^2	a	b	c	d	R^2
Height	HH	1.5	11.2	0.28	4.2E-03	-1.6E-01	1.98	-15.6	0.34
	HV	2.3	18.3	0.48	6.5E-03	-2.5E-01	3.06	-25.0	0.60
	VV	2.0	13.3	0.49	3.4E-03	-1.4E-01	1.91	-16.9	0.55
AG biomass	HH	0.7	10.8	0.50	3.0E-07	-2.0E-04	0.05	-10.2	0.50
	HV	1.1	17.4	0.80	1.0E-06	-6.0E-04	0.09	-16.8	0.74
	VV	0.8	12.0	0.61	1.0E-06	-5.0E-04	0.08	-11.8	0.69

Advantages & Limitations

L band and P band analysis offers the potential for biomass retrieval in forests however the backscatter from stands of similar biomass can vary depending on forest structure. Also the density of trees has a significant impact.

Biomass assessment using C BAND

Using C band SAR data, two methods are currently used: coherence measurements (multitemporal) and coherence modeling with an interferometric Water Cloud Model (IWCM). Coherence modeling shows advantageous for biomass assessment for densities up to 200 m3/ha. ERS-1/2 tandem coherence information has also been used for forest stem volume mapping showing good overall accuracies.

[Askne et al 1997] used data from the 3-day repeat cycle of ERS-1 and from the ERS-1/ERS-2 tandem mission. The SIBERIA Project (SAR Imaging for Boreal Ecology and Radar Interferometry Applications), at the beginning of this decade, was a pioneer project which demonstrated that with an ERS-1/2 tandem coherence image and a JERS backscatter image it is possible to derive forest growing stock volume classes up to 80 m3/ha with nearly 90% accuracy over a 106 km² area in Central Siberia. In order to achieve this, it was necessary to apply over hundred ERS images at a spatial resolution of 50 m [Wagner et al. 2003].

[Santoro et al 2010] presented a new approach which allows the training of a semi-empirical model on a frame-by-frame basis using the MODIS Vegetation Continuous Field product without further need of ground data. The new approach has been applied which is based on the multi-seasonal and multi-baseline ERS-1/2 tandem coherence. Current work concerns improvements to make the algorithm adaptive to the seasonal conditions of the ERS-1/2 coherence and to develop a quality flag for areas with strong topography.

Preliminary classification results of the ENVISAT ASAR data (also C band) showed a good agreement with previous results obtained from ERS-1/2 tandem data, thus making the HH/HV ASAR AP data suitable for forest map updates. Summer season data are better suited for this purpose [Santoro et al 2010]. An improved approach on forestry biomass using C band SAR was presented by [Santoro et al 2010]. The multi-temporal combination has been applied in the BIOMASAR algorithm. Forest Growing Stock Volume (GSV) maps of Central Siberia, Europe and Quebec have been elaborated from ENVISAT ASAR ScanSAR data with an accuracy of 20-30% for a resolution of 10 km.

Advantages & Limitations

Because of the large area and the multi-temporal characteristic of the ERS dataset, coherence strongly varies with meteorological and environmental conditions both in space and in time. A further limitation is the area covered by ERS-1/2 and the comparably low resolution. In addition, the use of more than 60 scenes is very bulky and difficult, especially for a user not familiar with SAR processing.

Work flow

Due to the advantages and limitations given above, it is recommended to use longer wavelengths like L and P in cross polarization HV (horizontal – vertical) mode, because it results mainly from canopy volume scattering and trunk scattering. [Le Toan et al 1992] presented models describing the relationship between forest biomass and SAR data.

A model for obtaining Above Ground Biomass for forests and height of the trees is presented by [Watanabe et al 2006]. There are adjusted coefficients of determination R^2 between σ^0 and the biophysical parameters and regression coefficients. The big advantage of using L band is the satellite data availability. At present Advanced Land Observing Satellite (ALOS) has been launched mostly for precise land coverage observation especially for forests. During its operational cycle, also the JERS satellite was operating in L-band therefore many images of forest areas have been archived.

Generally, there are two options to proceed when calculating the biomass from SAR:

(1) using existing models or

(2) setting up a new model for the area.

The dominant underlying method for these models is regression analysis, where a regression curve is fitted to a set of backscatter versus ground-measured biomass values. This curve (usually a line) is then used over adjacent forest stands to obtain the biomass value from the corresponding radar backscatter measurement. It has to be noted that the accuracy of the local results also depends on the number of points used in developing and checking the regression curve, which in turn translates into more field measurements. However, the field measurements are very often difficult to get. There are differences between biomass values obtained for the same area depending on the method used [Saatchi and Moghaddam, 2000]. Radar signals are highly affected by the canopy and soil moisture variations which are often difficult to measure. The same stand could produce a significantly different radar backscatter value depending on environmental conditions that effect either soil moisture or canopy moisture. Thus meteorological information should also be integrated in the set up and suitability analysis of a model.

For option (1) it is important that the existing model is flexible in terms of data, acquisition time, forest type and –density, etc. If this is not the case, additional in situ measurements should be conducted to improve the model and to extend the model to various geographical areas.

Setting up a new model (option 2) requires a correlation of radar data with several forest parameters to calculate the biomass or to directly correlate the radar data with biomass measurements. Forest parameters such as density, age and volume are important information for forest management and are thus standard parameters in national forest inventories.

Volume, defined as the quantity of wood within a given area, is considered as the most important forest parameter. Volume estimation methods are based on data from ground plots. Thus if the plot level information is available and up-to-date, it can directly be used for the SAR processing. The whole processing is depicted in a simplified manner in Figure 10, for further details the reader is referred to Deliverable D2.2.

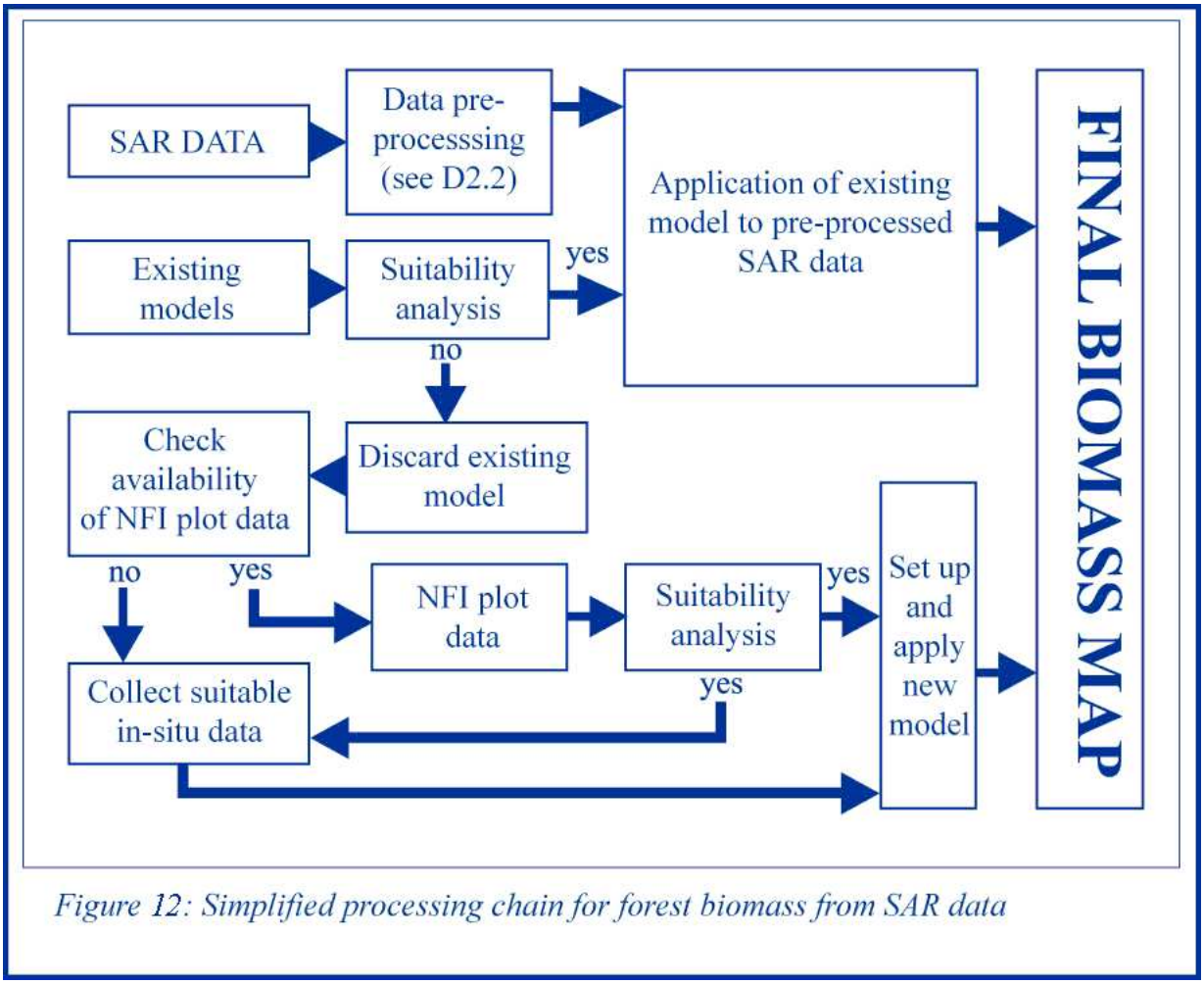


Figure 12: Simplified processing chain for forest biomass from SAR data

The main limitation of this approach is the saturation of the signal which occurs at about 100 t/ha in HV polarization. This limitation should be overcome with the new P-band satellite BIOMASS from ESA.

Based on the total biomass, the amount of biomass for energy can be estimated using existing equations or local expert knowledge as described in the basic approach.

6.3. *Advanced approach for agricultural biomass*

Similarly to the forest section, an advanced approach with more sophisticated methods for agricultural biomass is presented here. As described in D2.1, there are two different methodologies for the estimation of biomass using remote sensing data. One is the direct biomass estimation using empirical, semi-empirical or deterministic/physical modeling. The second would be an indirect approach based on post-classification biomass calculation. Figure 11 gives a rough overview of both workflows. For further detail on both approaches the reader is referred to D2.1.

In correlation to the basic approach, annual crops; permanent crops and grasslands are again treated separately in the respective sub-sections 6.3.1; 6.3.2 and 6.3.3.

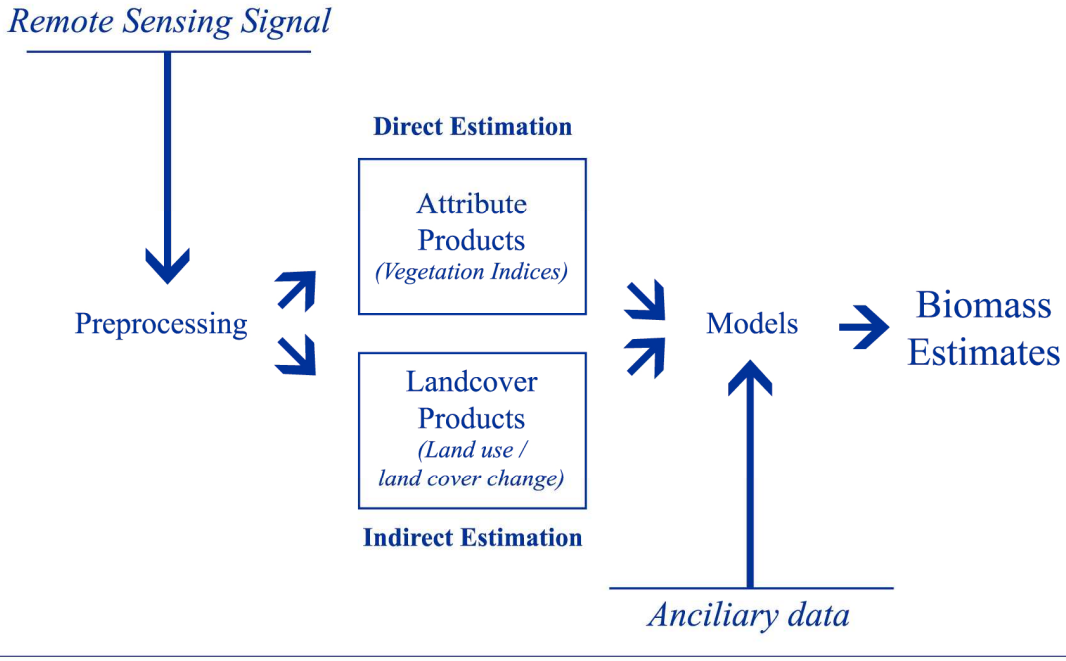


Figure 13: Flow of remote sensing information for biomass estimation adapted from Rosillo-Calle et al., 2007.

6.3.1. Annual crop residues

6.3.1.1. Direct biomass estimation

Direct biomass assessment can be done based on optical and/or SAR data. The idea behind it is basically the same as for the advanced approach for forest using SAR data. For estimating biomass statistical regression-based methods are the most commonly used remote sensing-based approaches [Wall et al., 2007]. They are based on empirical relationships between terrestrial data and reflectance based vegetation indices for optical data or backscatter for SAR data. Typically they are straightforward to implement without requiring numerous other inputs, such as management practice or soil information. The main drawback of these empirically-based approaches is that the assessed relationships are typically crop dependent,

local and are not easily transferable to other regions [Becker-Reshef et al., 2010], [Doraiswamy et al., 2003], [Moriondo et al., 2007]. Deterministic / physical models on the other hand have the disadvantage that they typically require numerous crop specific input information, such as soil characteristics, management practices, agro-meteorological data and so on [Becker-Reshef et al., 2010]. Despite extensive studies, crop models have rarely progressed successfully to operational implementation and are typically only applicable in the region for which they were developed.
For the harmonized assessment of the agricultural biomass potential within Europe a generalized (meaning without too much additional information) empirical, remotely sensed biomass estimation model for all kinds of crop types, which is still simple, robust, economical, widely applicable, transferable, not needing ground truth data and also meeting the user requirements in regard to spatial resolution and accuracy, would be needed. Some possible options with regard to data input and the main processing characteristics are given in this section, divided into:

A) using multispectral data and
B) using SAR data.

A) Using multispectral data
In Becker-Reshef et al., 2010 a model was built for the estimation of winter wheat yield in the USA based on low resolution MODIS time-series data and national statistics. As an additional input they also used a crop type map, masking out only the winter wheat regions. Using these low resolution time series data they obtained a low yield estimation error of 7% for the USA and when transferring the model to the Ukraine an error of 15%, equalling 0.44 MT yield/ha. For them the coarse resolution was sufficient, however it was not spatially explicit.

As the CEUBIOM users require a higher resolution we are faced with major problems when generating a generalized regression formula with fixed coefficients. This is due to the fact that moderate and high resolution data scales and single pixel of winter wheat will likely shift between crop types from one year to the next due to crop rotations. As the regression model is based on relating the wheat specific NDVI signal to yield, it requires a-priori knowledge of the winter wheat locations and more information on management practices [Becker-Reshef et al., 2010]. Another critical point is that the model probably will not work in regions featuring small field plots (< 30ha), or have very high yields and very dense green biomass (NDVI saturation). When working at this scale specific crop/environment information is needed requiring a large set of experimental/ground truth data, which also have to be assessed in a harmonized way. It must be stated, that the above mentioned model only worked for winter wheat and did not regard any other agricultural classes.

With respect to the CEUBIOM goals complex deterministic models show more potential, especially if it is possible to simplify them working with more generalized assumptions. One example is the AGRI4CAST model from MARS/JRC (http://mars.jrc.it/). It couples remotely sensed variables with crop growth models (WOFOST) for yield forecasting. Next to the remote sensing information which is needed for the interpretation of the vegetation conditions and biomass development, additional information about the weather, crops, soils and management options are integrated. The crucial issue is once again the spatial resolution as the results are aggregated on Nuts-3 level and are thus not spatially explicit [Gallego, 1999], [Carfagna and Gallego, 2005]. However by reducing the temporal resolution it might be possible to increase the spatial resolution and if we integrate with an a-priori classification we would be able to identify the crops of interest as defined by CEUBIOM. Thus the suggested approach would integrate remote sensing information at two points: First, using it for the

classification of the crop areas and second for the estimation of the vegetation condition for the crop growth and yield estimation models (see D.5.3).

B) Using SAR data

For high frequency SAR – Ku and X band – the backscatter signal is mainly a result of canopy scattering, while backscatter at low frequency - L and P band - is mostly dominated by soil effects and only to a small part by vegetation. Therefore lower frequency radar is better suited for soil moisture estimates, especially when the vegetation covers the ground, while the higher frequency could be applied for vegetation studies.

In general it was shown that a correlation exists between the radar backscatter signal and vegetation biomass. The higher frequencies like X or K_u band are used for discriminating lower biomass like wheat, grass, or root crop. Aside from the wavelength, the incidence angle of the SAR acquisition plays a crucial role in biomass assessments. For example, an X band image at VV polarization and incidence angle of 30^0 to 50^0 was found to work best for biomass assessments of cereals just after heading (Wu et al 1985). Tall vegetation with higher biomass values showed higher backscatter coefficients than low vegetation with small biomass values. Also it has been shown that in broad leaf crops, backscattering from stalks dominate at L band, while at C band leaves make a significant contribution to backscatter and attenuate the contribution of stems (Macelloni et al 2001).

The strong interaction of the wave signal with soil and vegetation is often presented in complex models which better characterize the contribution of the various parameters on the observed backscattering signatures than simple linear regressions. Therefore, combinations of multifrequency polarimetric SAR give better results of physical parameters related to biomass such as Leaf Area Index, crop height etc. The implementation of a water-cloud model (Atema and Ulaby 1978) extended by Ulaby et al 1986 offers the possibility to derive several vegetation parameters that describe vegetation and soil moisture values. The water cloud model represents the total backscatter from the canopy $\sigma°$ (m^2/m^2) as the sum of the signals coming from vegetation σ_v^o (m^2/m^2) and from underlying soil σ_s^o (m^2/m^2)

Recommendations & Limitations for using SAR data

- Short wavelength radar systems provide better biomass assessments
- The viewing angle should be between 30 and 50°
- Integration of different types of polarizations often improves the result
- Combination of several wavelengths has been reported to improve the assessment, but requires more complex procedures
- Interpretation of images requires knowledge of radar interaction with surfaces
- Speckle (dark and bright pixels) limits interpretation
- Limitation with regard to saturation effects when biomass is large
- Not well applicable in steep topography and rough terrain due to layover effects

6.3.1.2. Indirect/post-classification based biomass estimation

In the basic approach, the agriculture class ‘arable land’ is not further subdivided; hence the class actually includes cereals, sunflower, rape, potatoes, sugar beets, maize, fallow land and so on. This is due to the fact that the agriculture class is highly dynamic, thus the subclasses

change annually and even within a single year, i.e. if catch crops are sown. A pan-European classification of crops at high spatial resolution is therefore very complex and very time consuming.
Within the advanced CEUBIOM harmonization approach these land use classes will need to be further sub-classified – however masking out all other classes such as urban and forest. Within this indirect biomass estimation approach based on a post-classification analysis, the agricultural classes which are important from an energy point of view will be assessed. These are: cereals (summer and winter), barley, maize, rice, dried pulses, oilseed, rape, sunflower seed, potatoes, sugar beet and fallow. The big advantage of this approach in contrast to the basic harmonized approach is that it is more spatially explicit while also featuring more thematic detail.

The following paragraph contains an outlined description of the necessary preprocessing (for a detailed description see Annex 3) and the classification strategy, for a theoretic description of the classification strategy and data used refer to the deliverables: D2.1 (Methods compendium on current state-of-the art in EO for biomass assessment), D2.2 (Study on SAR potential for direct biomass assessment) and D2.3 (Recommendations on EO data for European users).
For the advanced approach for indirect biomass assessment, two different multi-temporal remote sensing data sets can be used - optical and SAR; both are usable. The data are first classified and in a second step the classes are associated with the respective biomass statistics. This approach has been chosen, as the results are then comparable with the basic CEUBIOM approach and no additional data, e.g. field data, are necessary.
A multi-temporal classification approach for a further discrimination within the agricultural class is essential, as the classes exhibit a very dynamic feature space during the vegetation period. In Figure 14. the multi-temporal characteristics of different land cover classes are shown. What becomes obvious is that, e.g. the classes ‘cereals’ and ‘rapeseed’ are mono-temporal and rather similar for most of the time. Only during May a discrimination of both is possible. However, during May the feature space of the classes rapeseed and root crops are rather similar, they can be more easily discriminated in April. Next to multi-temporal dynamics within each class a multi-temporal approach is also necessary to identify fields with catch crops, especially because these are very often used for bioenergy.

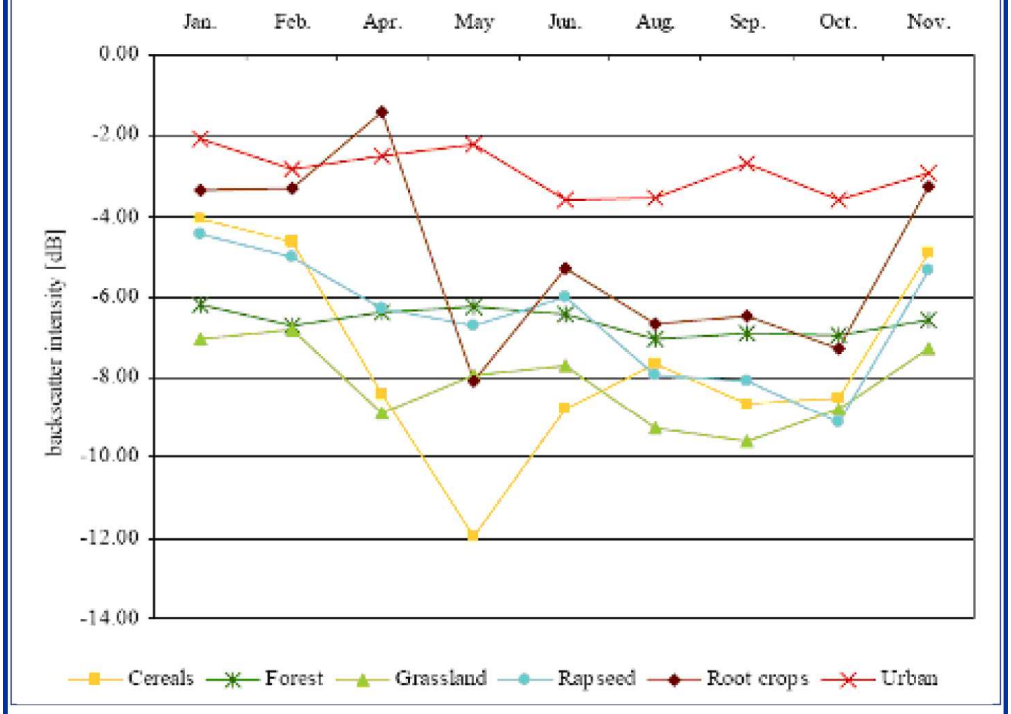


Figure 14: Comparison between multi-temporal characteristics of different land cover classes (ERS-2, C-Band, VV polarization, from Waske, 2007)

In general, **the input data** should consist of **at least three images** covering the following time spans: **early vegetation period, mid vegetation period and late vegetation period** in accordance to the phenology and the respective bio-geozones (see Figure 15).

An overview of the general phenological cycles for each country can be found at: http://www.pik-potsdam.de/~rachimow/epn/html/frameok.html
or at the European Phenology Network (EPN): http://www.dow.wau.nl/msa/epn/ [van Vliet et al., 2003].

These are generalized data based on time series assessments. Current information on the respective phenological stages is frequently updated in the MARS bulletin: http://mars.jrc.it/mars/Bulletins-Publications.

The satellite data should be chosen based on the country-specific vegetation cycle. Special attention should be given to choosing imagery from the right phenological stages of the respective cereals in a certain area[Lancashire et al., 1991]. When working with SAR images it is very beneficiary to have information from the heading stages as this phenological stage is very well detectable due to complex changes of vegetation geometry.

The image time series can either be based only on optical data (e.g. RapidEye), only on SAR data (e.g. TerraSAR-X) or a combination of both data types, whereby the multisource approach is the most advanced and will discussed further in D5.3 -Definition of gaps in European EO/biomass research and policies-, as this approach is still in a research phase.

Prior to the classification, a preprocessing is necessary. This may involve atmospheric and geometric corrections for optical data and a slant-to-ground range conversion, a sigma and

beta naught calculation as well as filtering procedures for the SAR data (see D2.1 and D2.2 for further detail on SAR and the Annex 3 for the optical data).
For the actual classification process an object-oriented classification approach is suggested. For further discussions and descriptions of other classifiers please refer to D2.2. In general, the concept behind the object-oriented approaches is to aggregate adjacent pixels with similar properties to 'image segments'. In a second step, the actual classification is performed, using not only the spectral, but also the spatial information pattern. The assumption is that the image is made up of relatively homogeneous 'patches', being larger than individual pixels. The approach is mimicking human visual image interpretation, using color, shape, texture, patterns and context information to group the environment. The environment is therefore created at multiple scales rather than single scale and better represents each individual object. For example, a small street needs to be captured at a different segmentation level then a large lake. Once the segmentation process has been successfully completed, the classification process starts, whereby different kinds of characteristics can be used. The object inherent properties, such as spectral and time series information, texture, shape and specific characteristics that describe the relationships among the objects, including their connectivity, their proximity to other objects and so on. By using a hierarchical classification form, e.g. starting with small objects, each class can be described by its optimal scale [Lillesand et al., 2008].
After the classification process an accuracy assessment is essential, either on a visual basis or using reference information. One of the most common means for expressing the actual classification accuracy is the classification error matrix / confusion matrix / contingency table [Congalton and Green, 1999]. Within the matrix, the independent reference data (independent ground truth data or visual interpretation by an independent analyst) are compared with the corresponding classification result for a given set of validation samples. The most commonly used evaluation criteria include: overall accuracy, producer accuracy and the user accuracy.

In a final step the land cover information has to be linked with the actual biomass values from statistics using the CEUBIOM basic approach. All relevant framework conditions must also be included at this stage

Special issue: catch crops
In some parts of Europe it is common to grow (winter) catch crops, which can be used for energy purposes. For considering these kinds of crops it is important to know where this agricultural system is in practice. Thus the suggested method is two-fold: 1) identify areas with catch crops and 2) identify the actual catch crop type with relevant data (in terms of geometric resolution and acquisition date).
The information for point 1) can come either from local experts or by using rather complex remote sensing techniques, i.e. spectral unmixing [Adams et al., 1986] and time series analysis. Input data should be of high temporal resolution, which is currently mainly low geometric resolution data such as Envisat Meris, Noaa Avhrr, Spot Vegetation or Terra/Aqua Modis.
The following procedure of identifying catch crop types is still far from being an operational remote sensing method. Also, there is currently no operational service to assess catch crops or the land management practices for the whole of Europe. Thus this topic is part of CEUBIOM Deliverable D5.3.

A) Workflow using multispectral data

Input data are high to medium resolution satellite sensor systems (20 – 60 m) that fulfill the User requirements (the order of the satellites is random):

- Landsat 7 ETM+ (gap-filled)
- Landsat 5 TM
- SPOT 4/5
- RapidEye (higher resolution)
- DMC – Disaster Monitoring Constellation
- EO -1/ALI
- Aster
- THEOS
- Future Sentinel -2

Timeframe:

1. Early vegetation period
2. Mid vegetation period
3. Late vegetation period

As explained above images should be chosen in accordance to the local/national phenological development and the bio-geozones.

Preprocessing (for further detail please refer to Annex 3):

As the advanced CEUBIOM approach works with multi-temporal data and requires integration of an additional information layer (mask of annual crops from other sources) a careful preprocessing including an atmospheric and a geometric correction is necessary.

Atmospheric distortions and effects influence the reflectance within each image as well as between different images, making the spectral reflectance profile of the different land cover classes incomparable to each other. In order to compensate for these atmospheric distortions induced by water vapor and aerosols in the atmosphere and by seasonally different illumination angles (scattering, illumination effects, adjacency effects), an atmospheric correction should be applied to each image using i.e. ATCOR [Richter, 2006]. This preprocessing step performs a calibration of the data with respect to an artificial surface reflectance without atmospheric distortion effects. This calibration method facilitates scene comparability, which is crucial for multi-temporal analysis.

The next essential preprocessing step is the geometric correction of each image. For the actual correction, control points have to be collected in the reference and the input image. This can be done either manually or automatically. In a next step the transformation parameters are estimated and the image is corrected accordingly. For the calculation of the new pixel values different resampling approaches can be used, e.g. nearest neighbor, cubic convolution, bilinear. The cubic convolution approach is commonly used, as it produces no artifacts while nearly keeping the original pixel values.

Segmentation/Classification:

A multi-resolution segmentation is necessary for the detailed classification of the agricultural class. For the first segmentation level the outlines of the annual crop areas are used in a mask – image objects in accordance with the shapefile outlines are generated by using a chess board algorithm. In a next step, a further sub-segmentation within the ‘arable land’ class is performed using a multi-resolution segmentation. Based on these sub-segments the ‘arable land’ class is further divided. The actual classification process should be twofold. In a first step a simple nearest neighbor classification based on training samples can be done using the

three time points and their respective NDVIs (Normalized Difference Vegetation Indices). If beneficiary also other Vegetation Indices can be calculated and integrated. The samples for each class can either stem from reference data, or be directly extracted from the image by an expert. A fine-tuning should follow the basic classification using explicit class descriptions for each class. Especially the multi-temporal patterns of the agricultural classes should be considered. For monitoring these kinds of dynamics different techniques are used, such as statistical approaches, e.g. multi-temporal standard derivation, spectral-frequency techniques or wavelet decomposition [Martinez et al., 2009]. In general the characteristics of the phenological cycles can also be addressed by calculating the 'NDVI metrics', i.e. the date of greenup, characterized by a sudden NDVI increase or a surpassing of a certain threshold value, the date and magnitude of maximum NDVI, the temporal integration of NDVI, the length of the growing season and the rates of NDVI change [Galford et al., 2008].
If necessary a manual post-processing can be done as a final step.

Accuracy Assessment:
In order to finally judge the classification result a validation using a statistical approach – accuracy assessment - is necessary. The determination of the accuracy is based on a random sampling comparison of the class affiliation between the individual pixels and their 'real' pendants. The 'real' pendants can either be ground truth points or be extracted from other reference material. For the CEUBIOM accuracy assessment the following data sources could be used:

- LUCAS data, if available for the respective year,
- other national reference data, i.e. additional high resolution imagery, or ground truth points,
- ground truth data collected in the field for this specific study or
- the same remote sensing data could be used and interpreted by an independent specialist

Additional information can also come from the CIS- Agri-Env service from GEOLAND, displaying information about the European crop rotation pattern.
A crucial point is that pixels used for training of the classifier should not be used for the subsequent accuracy assessment, as this would influence the results. For the actual illustration of the accuracy a confusion matrix is often created, indicating the error of commission and omission as well as the overall accuracy and the kappa-index.
In general the overall classification accuracy should be in the range of 85 ~ 95%, in dependence of the heterogeneity of the area and the post-processing effort.

Linking to actual biomass:
The final linking to actual biomass values will be done in accordance to the CEUBIOM basic approach.

B) Workflow using SAR data
Input data that fulfill the User requirements (the order of the satellites is random):

- TerraSAR-X
- COSMO-SkyMed
- Radarsat-2
- Envisat/ASAR
- ERS-2/SAR
- ALSO/PalSAR
- Future Sentinel-1
- Future BIOMASS satellite

When working with multi-temporal SAR data it is necessary to use the same frequency, i.e. C-band, X-band or L-band and the same polarization (HH, VV or cross-polarization) for all aquisitions.
For mapping of the crop type a short wavelength band such as Ku; X and C is most often used, but also L band can be used [Holmes, 1990]. [Brisco and Protz, 1980] used L and X band for corn classification, as on the L band corn and forest were well distinguished from other classes. Corn was distinguished from forest by a texture signature analysis on X band imagery – corn was found to have a smooth texture, forest a rough one. The lower frequencies such as L and P band are used to discriminate crop types with high biomass such as sunflowers, canola and maize. Also, different polarizations provide valuable information for crop classifications, e.g. HV polarization proved crucial for distinguishing corn from forest in the above mentioned study.

Timeframe:

1. Early vegetation period
2. Mid vegetation period
3. Late vegetation period

As explained above, images should be chosen in accordance with the local/national phenological development and the biogeozones.

Preprocessing:
In addition to the geometric correction of SAR data various other preprocessing steps are essential and depend on the initial processing level of the input data. For a detailed description of the respective preprocessing steps please refer to D2.2. However, for operational use it is recommended to use either Geocoded Ellipsoid Corrected (GEC) or Enhanced Ellipsoid Corrected (EEC) data. The GEC products are multi-look products, resampled and projected to a reference ellipsoid. In contrast, the EEC products are orthorectified multi-look images, in which image distortions caused by varying terrain height are compensated using a digital elevation model.
These products, therefore only need to be calibrated, meaning the DN values have to be converted into Beta Naught (Radar Brightness) using the sensor specific calibration constant. Beta Naught is then finally corrected to Sigma Naught (Radiometric Calibration). This calibration step is necessary as the backscatter from a target is influenced by the relative orientation of the illuminated resolution cell and the sensor, as well as by the distance in range between them. The derivation of Sigma Naught thus requires detailed knowledge of the local slope, i.e. local incidence angle. As a final pre-processing step a speckle filtering can be done, suppressing the noise inherent in SAR data, which is due to multiple interactions of the scatterers within one resolution cell, interfering with each other in either a constructive or a destructive manner. Constructive interference results in a strong return signal and a bright pixel in the image. Destructive interference results in a weak return signal and dark pixels in the image. A speckle filtering is a compromise between speckle removal by reducing the radiometric resolution and high spatial resolution.

Segmentation/Classification:
The proposed workflow for the SAR data is actually very similar to the optical approach. A straight forward classification is suggested. More complex approaches i.e. also integrating change information (coherence or amplitude change images) are mentioned in D2.2 and will be described in D5.3.

Also for SAR data a multi-resolution segmentation is suggested, using existing outlines for masking out the arable land class at the first segmentation level. Building upon this segmentation level a further sub-segmentation within the segments of the arable land class has to be performed. For further class discrimination additional indices as the Haralik parameters or temporally induced differences in backscatter between two or three images can be calculated. The actual classification of the images should also be two folded using in a first step a simple nearest neighbor classification based on training samples and in a second step introducing explicit class descriptions for the fine-tuning of the classification. If necessary a manual post-processing can be done as a final step.

Accuracy Assessment:
See multispectral data for a rough description of the approach.
The overall accuracy using SAR data will in most cases be slightly below the accuracies of only using optical data, ranging between 80~90%, also in dependence of the final post-processing.

Linking to actual biomass:
The final linking to actual biomass values will be done in accordance to the CEUBIOM basic approach.

6.3.2. Permanent crop residues

The class ‘permanent crops’ as one spatial information layers is already existing in CLC and was originally also foreseen as part of GEOLOAND2 Euroland HR land cover layer. Due to recent developments, permanent crops will not be one of the five high priority HR land cover classes in GEOLAND2 any more. Nonetheless, CLC is available and thus this chapter focuses on the distinction of the individual crop types within the class permanent crops.
Permanent crops are much easier to classify than annual crops, because

- They are permanent, i.e. time of data acquisition is not so critical and updates have to be made much less frequently.
- There are only three main types: orchards, vineyards and olive groves
- They have a relatively clear structure
- They are often planted in specific climatic regions (e.g. there are no olive groves in Germany)

The use of very high-resolution multispectral sensors like SPOT V, Ikonos, Quickbird or even orthophotos allows the extraction of features such as spectrum information, texture, and geometric shape from the images for identifying several classes of permanent crops. Currently, the usual way to accomplish this task is with supervised classification techniques.

Orchards and vineyards are a common land cover class identified on governmental survey maps and the European Commission has stressed the importance of information derived from orchard and vineyard distribution maps for development of European agricultural policies.
The Joint Research Centre (JRC) provides the DG AGRI (Direction General of Agriculture of EC) and the Member States (MS) with technical assistance for policy making and implementation. The JRC was involved in statistical surveys and in the implementation of registers of permanent crops which are the basis for the management and control of these subsidies schemes (the vineyard registers, the olive registers and NUTS GIS).

For the management of the olive sector, the use of Remote Sensing and GIS has been extensive in the OLISTAT and OLIAREA projects in the period 1997-1999. OLISTAT stands for the estimate of the number of olive trees in the EU, OLIAREA stands for the estimate of the olive area and the number of maintained trees in the EU.
The methodology for the OLISTAT project was based on a high-resolution black and white orthophoto acquisition, computer aided photo-interpretation of the number of olive trees within a selected systematic sample, field visits and extrapolation to national levels using statistical estimators. For these projects, the JRC designed an automatic counting tool called OLICOUNT, for counting olive trees on the basis of 1m aerial orthophotos (Peedel et al., 2000) and a tool called OLIAREA to derive the olive area from the position of olive trees.

The vineyard register has a longer history. Originally the use of GIS was not compulsory for the implementation of the vineyard register, but recent regulation encouraged its use. Nowadays, with the obligation of compatibility between the vineyard register a majority of Member States have already set up a vineyard GIS, sometimes using VHR data (0.5m and even 0.1m pixel resolution for some small vineyards). At the end of 2004, the JRC launched a feasibility study for the NUTS GIS in order to define how to implement the NUTS GIS and how to control this scheme, using Remote Sensing and GIS techniques. For subsidized citrus plantings the requirement is to declare the area and trees at parcel level.

The outputs of the above mentioned projects and activities, 100% financed by EC, are today the basis for registers of permanent crops of vineyards and olives trees in France, Italy, Spain, Portugal and Greece. This was the scope of Reg. (CE) 2366/98. Subsequently the management of registers passed to local authorities and is still administered by them.

Methods of **counting of lone-standing trees** (either olive or any fruit trees) are based on a combination of image threshold (i.e. using the spectral characteristics of trees), region growing and tree morphological parameters (i.e. using the morphology of individual trees). More details on the method can be found in (Peedel et al., 2000). It operates with four parameters:

- Grey value threshold (minimum, maximum)
- Tree diameter (maximum, minimum)
- Crown shape (maximum, minimum) calculated with the ratio between minor and major axes
- Crown compactness (range) calculated with the ratio blob surface to envelope surface.

This is a semi-automatic approach where an operator is required for tuning the parameters per parcel during the training step and for manually checking the results. OLICOUNT was adapted to support VHR images and the JRC carried out some tests with other fruit trees species (nuts and citrus).
Other investigations were also carried out by the JRC with the intent of reducing the manual work. Mathematical morphology was tested, using the method of regional minima based on the principle that since crowns are dark objects, they usually contain a regional minimum. A regional minimum is defined as a connected component of pixels whose neighbors all have a strictly higher intensity value [Soille, 2003].

Workflow

As an inventory (register) of vineyards and olive groves is available for France, Italy, Spain, Portugal and Greece, they can directly be used instead of the less detailed CLC. For the remaining countries, the same methodology should be applied (semi-automatic assessment) in order to guarantee comparability in the results. The main steps for such a method are described below. Since orchards have similar properties, the methodology can also be applied, although might need some adaptations in different ecozones.

With VHR images it is possible to separate the crowns of permanent crop trees from other classes and from the background vegetation in the image using a Gaussian process classifier. This separation is done based on textural and morphological features. The method consists of identifying the boundaries of the canopy from the shadows on the periphery of each tree. Each image model is defined by both geometric and radiometric aspects. The geometric aspects consist of the crown envelope shape and the sensing geometry, while the radiometric aspects consist of the scene irradiance, the interaction of the scene irradiance and the tree crown, and the sensor irradiance. The typical flow chart for this approach is shown in Figure 125.

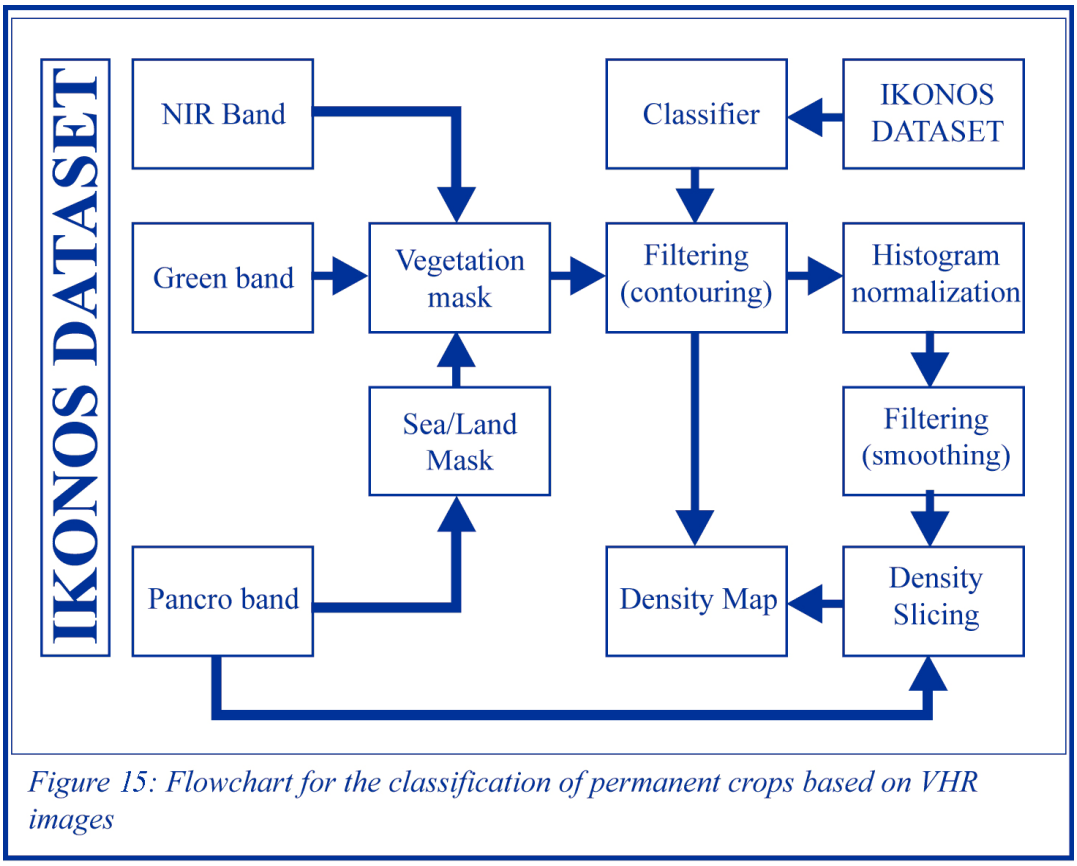


Figure 15: Flowchart for the classification of permanent crops based on VHR images

This procedure was applied in a case study of the European Project called EOBEM (Earth Observation for grassland, shrub land and woodland biomass estimate and management, see http://events.eoportal.org/get_announce.php?an_id=5389, [Borfecchia et al., 2001]) that aimed at defining and mapping the vegetation distribution and estimating the related biomass in three different European test areas. Figure 136 shows an automatic classification product of this project on IKONOS panchromatic imagery with identified Aleppo Pines marked with

crosses and a regular pattern of olive plantations with dots (red or blue). In particular the Aleppo Pines are marked by crosses of different size, according the extension of their crowns and their relative biomass calculation. The big olive trees are marked by red dots and the small ones by blue dots.

Figure 16: Olive tree detection based on IKONOS panchromatic image (from EOBEM project)

In most cases, a simple texture measure can not provide enough information on ground object discrimination. Better segmentation results can be obtained by considering multi-feature fusion. For this case there are many texture analysis techniques that are used for the extraction of features and which are well-described in the literature: statistical methods (grey level co-occurrence matrix, grey level difference vector), filtering techniques (energy filters, Gabor filters), wavelet decomposition- based methods, etc.

It has been shown in the above mentioned projects, that automatic detection combined with visual refinement is a very good method to assess the individual trees in olive groves and citrus plantations in the Mediterranean region. It can be expected that this discrimination is a bit more difficult for orchards in other ecozones, because the background vegetation is more similar to the spectral information of the trees. In this case, height information (from LiDAR data or through photogrammetric procedures) can help discriminate trees from the vegetated ground.

6.3.3. Grassland

Regarding the direct biomass estimation of grassland the same concerns as for annual crop residues have to be considered (see Chapter 6.3.1). Also grasslands can vary greatly and often feature a different species type, which makes the extraction of a generalized retrieval model

for the whole of Europe very complicated. However, there are successful implementations on regional level, e.g. in Italy [Schino et al., 2003] and also in Lappland [Colpaert et al., 2003]. Sometimes, a combination of indirect (first classification of different grassland types) and direct biomass assessments (within each class) is used [Jianlong et al., 1998]. This is most probably very useful, as it is foreseen in GEOLAND2 to provide two grassland classes: intensive and extensive grassland. In addition, hyperspectral data has been used in scientific studies. [Wamunyima, 2005] gives an overview on the state-of-the-art on this topic.
The problems with most of these approaches are the related intensive field measurements and the high costs. Up to now 'normal' grass is not yet considered as very important for energy purposes, thus this effort would be difficult to justify. However, in case of an increased demand of grass for energy purposes in future, such a method, currently still in a research stage, should be further developed towards an operational level.

6.4. Energy crops

This section will focus on remote sensing based methods for vegetation types that have a high energy yield and are thus primarily used for biomass for energy production. These include the agricultural crop Triticale (*Tritosecale sp.*), the Miscanthus grass species (*Miscanthus sp.*) and the group of short rotation coppice species (SRC), which includes Willow (*Salix sp.*) and Poplar (*Populus sp.*) species.
The basic problem with these energy crops is their similarity with other vegetations types used for different purposes, such as triticale vs. wheat; Miscanthus vs. other grasses and SRC vs. 'normal' young deciduous forest. Their similarities are logical, since the plants are either the same or closely related species. Thus the only chance to estimate the amount of biomass from energy crops is to get the area information for energy crop production zones from local experts and then calculate the amount of biomass for these specific areas. Miscanthus could be an exception, which can be distinguished directly from remote sensing, as some studies suggest.

Existing studies

Triticale
The earliest study regarding the use of remote sensing specifically on the *Triticale* species was conducted by [Railvan and Korobov, 1993]. At the time the crop was not aimed for bioenergy production and the study merely assessed the relationship between the red edge inflection point location and the growth stage of the plant. A relationship between the red edge position and biomass has already been indicated in the past suggesting that an increase in chlorophyll concentration or biomass, results in the shifting of the red edge to longer wavelengths [Dawson and Curran, 1998]. As a result the red edge position has been used as an indicator for chlorophyll concentration, leaf area index (LAI) and biomass [Curran et. al., 1991; Danson and Plummer, 1995].

The *Triticale sp.* species has many structural and phenological similarities with wheat. This is possibly the cause for the lack of research on methods using remote sensing data for monitoring this particular species. On the other hand, application of remote sensing data in monitoring crop yield and biomass has been evident for many years. A study by [Serrano et. al., 2000] has shown questionable results when the traditional vegetation indices were employed for the assessment of LAI of winter wheat, but promising results for the estimation of chlorophyll content (amount of chlorophyll per leaf area unit), absorbed photosynthetically active radiation (APAR) and grain yield. More recent studies showed several Water Indices to be related with grain yield [Prasad et. al., 2007; Gutierrez et al., 2009]. Also the introduction

of SAR data for biomass and crop yield monitoring, particular in conjunction with optical data has produced some promising results [McNairn et. al., 2008; Laurila et. al., 2010].

Miscanthus

The Miscanthus grass has a high LAI value of around 8, when maximum yield is achieved and is also very densely planted (1 metre distance approximately, giving 10,000 plants per hectare). Reflectance spectra of Miscanthus plants were found to be closely related with the LAI, as well as the amount of absorbed photosynthetically active radiation [Vargas et. al., 2002; Jorgensen et. al., 2003]. The main research was conducted in methods of using reflectance data for the assessment of dry matter production between various genotypes of Miscanthus, in an effort to identify the most productive breeds.

Studies on Miscanthus plants found naturally in Japan's wetlands, focused on its discrimination from the Phragmites species which co-exist in those areas. Since these two vegetation types are similar in structure, they can be easily confused. In the study of [Lu et. al., 2006] the matched filtering (MF) method of spectral mixture analysis was applied on an airborne hyperspectral image, in an effort to identify the percentage cover of each species within each pixel of the image. The method showed that Miscanthus stem volume and shoot density were closely correlated with the image-based percentage cover. In addition, stepwise multiple linear regression was used to estimate the shoot density and biomass. The independent data sets included original reflectance, band ratios, significant components identified by principal components analysis (PCA), and significant components identified by decision boundary feature extraction (DBFE). The coefficient of determination (R^2) and the root-mean-square error (RMSE) of model calibration and validation were used to evaluate the models. The significant DBFE components showed better ability at predicting shoot density of the two grasses than the other variables in the validation areas [Lu et. al., 2009].

Short Rotation Coppice

Methods of monitoring SRC and estimating biomass potential through the use of Earth Observation are similar to those for most woodland types. Studies focusing particularly on willow and poplar have found a significant relationship between the Normalized Difference Vegetation Index (NDVI) and LAI, which is also encountered for other tree species [Nagler et. al., 2004]. Direct estimates of biomass through the use of vegetation indices have also been successful for willow [Mirik et. al., 2005].

Some indirect methods of estimating biomass potential employ empirical relationships established using a particular set of data, between vegetation indices and biomass [Marsden et. al. 2010] or other parameters directly linked to biomass, such as photosynthetic activity or mean diameter-at-breast height [Grace et. al., 2007, Cho et. al., 2009]. Remote sensing based estimation of the amount of energy absorbed by the plant can provide an indication of the Net Primary Production (NPP), which is directly related to the amount of biomass [Gehrung and Scholz, 2009].

Another group of methods employ multi-spectral or hyper-spectral images to classify the various types of vegetation, calculate the area occupied by the vegetation type of interest and estimate the amount of biomass present, assuming a certain amount of biomass per unit of area occupied by the vegetation [Cho et. al., 2009]. A study has used multi-temporal bi-seasonal images to improve the classification accuracy of willow [Noonan and Chafer, 2007].

A third category of methods usees models to calculate biomass through the use of various parameters [Landsberg and Waring, 1997]. Some of these models directly employ reflectance

data for calculation of difficult-to-measure parameters and thereby increase the accuracy of the estimates [Castel, et. al., 2001; Waring et. al., 2010].

Workflow

Due to the already mentioned similarity to other crops and the heterogeneity among the energy crops, it is not possible to propose one workflow for these crops. Instead, it is proposed to

- Treat Triticale in the same way as other annual agricultural crops especially taking care of the timing of the multi-temporal data sets. In addition, local expert knowledge on the general occurrence of Triticale in a given region can significantly reduce the effort and/or improve the results.
- Treat Miscanthus also like an agricultural crop – using a direct approach based on optical (vegetation index) or SAR data. The only difference would be not to reduce the total biomass by a crop-to-residue ratio, but instead use the whole amount, so the total crop for energy.
- Treat SRC separately, although SRC areas are probably part of existing forest maps. The risk of confusion with young forest stands is high, thus a combined spectral-textural analysis should be made for all young deciduous forest areas in regions with known SRC existence (knowledge from local experts). This check could be done for all of Europe too (in order to avoid the use of local experts), but it is a matter of cost/benefit, whether this makes sense. After the areal extent of SRC is identified, it can be combined with an annual yield of biomass to generate an annual biomass map available for energy (since almost all SRC is used for energy).

7. Expected Product List

This chapter provides examples of the products to be expected as an output from the implementation of the assessment works described in this report.

The maps are based on national maps. However, as a common coordinate system, UTM should be used. If all data is in UTM, the maps can be easily transformed to a common European map coordination system such as the European Terrestrial Reference System 1989 (GEOGCS[‘GCS_ETRS89’,DATUM[‘ETRS89’,SPHEROID[‘GRS_1980’,6378137.0,298.257222101]],PRIMEM[‘Greenwich’,0.0],UNIT[‘Degree’,0.0174532925199433]]) as used in many pan-European databases such as the IMAGE2000 data set.

Map Products

Product: Forest Biomass for Energy - Map
Product ID: FM1
Approach: basic and advanced
Description:
This product includes the average annual domestic forest and primary forest residues expected to be available for energy purposes. Not included in this product are residues from saw mills and wood, pulp and paper industry. There is no point of spatially mapping the latter residues over the entire forest area, since they are plot based and occur at a specific processing plant (e.g. saw mills, etc). The base map will have a MMU of 1 ha (in line with the forest area map).

Product: Agricultural Biomass for Energy - Map
Product ID: AM1
Approach: basic and advanced
Description:
This product includes the average annual primary agricultural residues, primary residues from permanent plots and grasslands expected to be available for energy purposes. Not included are (secondary) residues from food industry. There is no point of spatially mapping the latter residues over the entire forest area, since they are plot based and occur at a specific processing plant. The map will have a MMU of 1 - 5 ha (depending on the base map used).

Product: Map of Biomass from Energy Crops
Product ID: ECM1
Approach: advanced
Description:
This product includes the annual amount of biomass expected from specific energy crops grown solitarily for energy use. These energy crops include Miscanthus grasses, Triticale and SRC. Since due to their very different characteristics (permanent vs. annual, grass vs. trees) all three types have to be treated differently, the resulting maps will also be slightly different; however they can be combined into one layer of energy crop biomass once converted to energy units like kJ.

Statistical Products

Product: Forest Biomass for Energy
Product ID: FS1
Approach: basic and advanced
Description:
This product includes the aggregated data from the 'Forest Biomass for Energy - Map' (FM1) plus all industry residues, which can also stem from timber imports. Since the statistics on imports and exports are only available on a national basis, the statistics will be national figures.

Product: Agricultural Biomass for Energy
Product ID: AS1
Approach: basic and advanced
Description:
This product includes the aggregated data from the 'Agriculture Biomass for Energy - Map' (AM1) plus secondary plot-based agricultural residues, which accrue at processing plants (e.g. oil mills) and can also stem from imports. Since the statistics on imports and exports are only available on a national basis, the statistics will be national figures.

Product: Biomass from Energy Crops
Product ID: ECS1
Approach: basic and advanced
Description:
This product includes the whole amount of energy from energy crops either through a statistical survey as suggested in the basic approach or an aggregation of the map results from the advanced approach.

The actual specifications of these products can only be defined after a series of targeted workshops with decision makers and bioenergy experts.

8. Discussion on costs and local expert knowledge

This deliverable is a first proposal for a harmonized biomass potential assessment framework for bio-energy in Europe. It should be considered as a basis for discussion and a guideline for implementation. The next step should be the development of the specifications of the foreseen products followed by the actual implementation of the method(s) in one or more countries and/or regions throughout Europe. The lessons to be learned from the implementation exercise could be used to revise the original product range and their specifications eventually resulting in strict (but realistic) guidelines as to the methods used and type of data generated in national bioenergy surveys. Depending on the financial resources available and the level of political commitment this could be done in 2-4 years, after which "official" bioenergy assessments would be carried out in a compatible manner in all over Europe.

The significance of such coordination of bioenergy studies and data gathering would be enormous. As results any national surveys could be readily aggregated to European level providing very accurate information for policy making without the need to launch top-bottom assessment campaigns. At the same time - if the overall approach outlined in this document and other CEUBIOM deliverables is followed – the acceptance for the proposed procedures

would be very high as existing national practices would not need to be completely replaced. For countries where such practices do not exist at the moment these specifications could be readily adopted as a national standard.

An over-ambitious, over-regulative approach would likely to be met with significant resistance by stakeholders and also the expert community. It is a proposal of the CEUBIOM consortium that such harmonisation is carried out in several phases combined with implementation monitoring before a new phase is enforced.

During the establishment of the procedures proposed for harmonisation cost-efficiency was continuously considered. A detailed cost analysis and accuracies values can only be given after a successful demonstration phase. However, based on previous studies and experience, a rough summation of data costs and man-hours needed for the assessments are given below in Section 8.1. A short overview of the areas where local expert knowledge would be needed can be found in Section 8.2.

8.1. Costs & Accuracy

Costs and accuracy values can be given in detail for input data and roughly for specific processing steps. There are several obstacles to a complete and detailed analysis of costs and accuracies for the CEUBIOM basic and advanced approach:

1) The methods and data are different for each biomass type, which is especially true for the advanced approach.
2) The accuracy of the input data is always affecting the accuracy of the output → since no mapping was done (this was not planned in the project), a final accuracy can not be given. However, an overview of the input accuracy is provided.
3) Due to the fact that no actual mapping was foreseen in the project, the specific costs can not be verified.
4) The costs for data processing are always highly dependant on the institution carrying out the analysis; on the salary system in different countries and on other employment related issues that are unknown.

The accuracy and costs of statistical/terrestrial input data is summarized in Table 26. EUROSTAT data is generally available for free.

Table 26: Costs and accuracies of statistical/terrestrial input data

Input data	Costs	Accuracy
EUROSTAT	Free	For quality reports see http://epp.eurostat.ec.europa.eu/portal/page/portal/quality/quality_reporting
NFI aggregated data	Free	According to national regulations, generally high
NFI plot data	Nationally different	According to national regulations, generally medium high
FMP data	Typically free	According to national regulations, generally high
National statistics	Typically free	According to national regulations, generally high
BEFs	Typically free (literature)	Varying, fallback on IPCC BEFs is always possible

The costs for remote sensing data, if purchased for operational use, are given in Table 7. These are the prices for new acquisition and for one purpose only. It has to be kept in mind, that most remote sensing data is acquired for several different purposes, e. g. the expensive LiDAR data sets are purchased for a variety of applications such as terrain mapping, flood risk assessment, forest applications and even demographic applications using the volume of buildings. By cost sharing, individual applications can be performed with much lower budgets. In addition, existing European data sets such as Image2000 or CLC are available for free from http://image2000.jrc.ec.europa.eu/. GEOLAND core service products will also be available at no cost in future. Outputs from existing projects as referred to in this document, e.g. the OLISTAT project should also be used in order to minimize costs. Partly such project data is available; partly the usage will have to be negotiated with the respective institutions.

Table 27: Data sets and respective operational image costs per km² (from CEUBIOM D2.3)

Satellite sensor	Forest/ non-forest	Forest types	Forest biophy. Parameter	crops/ non-crops	Crop types	Crop biophy. Parameter	Spatial resolution	Temporal resolution	Data costs [€ / km²] (new acquisition)
Low resolution sensors									
DMC – Disaster Monitoring Constellation	m1			m2			32m	5 days	0.121
ENVISAT MERIS	m1			m2			300m-1.2km	3 days	0.434
IRS-1C/IRS-1D - WIFS	m2			m2			188m	24 days	0.134
IRS-P6 - AWiFS	m2	m3	m3	m2	m3	m3	56m	24 days	0.15
NOAA-6 to 18 – AVHRR							1.09km	Daily	0
SPOT 5/SPOT 4 VEGETATION 2							1km	Daily	0.00025-0.00062
Terra/Aqua MODIS	m1			m2	m2		250-1000m	1-2 days	0.0128
Medium resolution sensors									
ALOS AVNIR	m1			m2			10m	2 days	0.102
EO – 1/ALI	m1	m1	m3	m2	m3	m3	30m	16 days	0.086
FORMOSAT-2	m1			m2			8m	Daily	?
IRS-P6 - LISS 3	m1	m1	m3	m2	m3	m3	23.5	24 days	0.15
Landsat 5 TM	m1	m1	m3	m2	m3	m3	30m	16 days	0
Landsat 7 ETM+	m1	m1	m3	m2	m3	m3	30m	16 days	0
RapidEye	m1	m1	m3	m2	m3	m3	6.5m	Daily	0.95
SPOT 5 HRG	m1	m1	m3	m2	m3	m3	10-20m	5 days	0.75
SPOT 4 HRVIR	m1	m1	m3	m2	m3	m3	10-20m	3 days	0.75
Terra Aster	m1	m1	m3	m2	m3	m3	15-90m	4-16 days	0.083
THEOS	m1			m2			15m	26 days	N/A
High spatial resolution sensors									
IKONOS	m1	x		m1			3.2m	3 days	12.92
KOMPSAT-2	m1	x		m1			4m	3 days	0.262
Orbview 3	m1	x		m1			4m	3 days	7.88
QuickBird-2	m1	x		m1			2.3m	2-3 days	16.54
Digital aerial imagery, e.g. ASC	m1	m1	m1	m1	m1	m1	10-30cm	On request	150 -200
LIDAR	m1	m1	m1	m1	m1	m1	10-30cm	On request	300 – 400
very good	medium	poor		m2=multitemporal minimum 2 images required					

The following table gives an overview on the processing costs for the main processing steps (or groups of processing steps) in a relative manner, since due to the reasons given above, absolute values are not available. Furthermore, an attempt is made to assess the accuracy of the different outputs relative to each other.

Table 28: Rough estimation of relative costs and accuracies of the main processing steps

Processing step(s)	Costs (**** high - * low)	Accuracy (**** high - * low)
Pre-processing for both approaches (if needed)	**	N/A
Processing of basic approach (forestry, agriculture)	*	**
Processing of basic approach of energy crops	*	*
Advanced approach forestry with LiDAR data	**	****
Advanced approach forestry with SAR data	**	**
Advanced approach annual crops with optical data	***	**
Advanced approach annual crops with SAR data	**	*
Advanced approach permanent crops with optical data	***	***
Advanced approach grasslands with optical data	***	**
Advanced approach energy crops	**	**

8.2. Quality assurance system for local expert knowledge

Based on the review of available data and the user requirements, it becomes clear, that there is a large amount of information needed, which cannot be harmonized throughout Europe without producing extremely large errors. These ‘not harmonizable’ frame conditions have to be deduced from **scientific literature and through local experts**, who have specific knowledge on the area and situation in question.

The advantage of scientific literature in this context is that the information is well accepted, it has generally undergone a review process and is thus a reliable source of information. However, the disadvantages of scientific studies must not be neglected in a practical implementation approach:

- results may not be up-to-date;
- investigations often cover only part of the information needed;
- results may apply only for a specific area or time period or only one thematic field;
- suggested methods are often not tested for large area operational applications.

Thus, scientific literature should be used, wherever possible and applicable and should be completed and/or updated by local experts (local expert knowledge = LEK).

Once the need for local expert knowledge in addition to scientific literature is confirmed, the next important step is to identify suitable local experts. From the user requirement questionnaires, it became clear that many national users have already done biomass potential assessments, most of them together with partner institutions. Thus it can be assumed that the users already have a set of experts at hand. Since different assessment methods by local experts can lead to significant differences in the final results, we here propose a framework for quality assurance that integrates guidelines for dealing with local expert knowledge. The overall framework is sketched in Figure .

This paradigm is similar to that implemented by the 3 Rio Conventions that have been established in the *Rio Summit, Rio Conference, Earth Summit, held by the UN on the 1992*:

- UNFCCC: United Nations Framework Convention on Climate Change
- CBD: Convention on Biological Diversity
- UNCCD: United nations Convention to Combat Desertification

These conventions have been established and are periodically refined to provide a set of rules and guidelines for achieving sustainable development related to their specific topics. The conventions directives are locally implemented via national bodies, (e.g. the National Convention to Combat Desertification). A national convention is formed by scientific experts that periodically meet in order to establish standards and reporting rules for assessing the status of their own country in order to report it at global level (the UN in this case).
The local experts are appointed by the administrative National bodies (e.g. Ministry of Environment) and define in each country the specific parameters to be used and their critical values (e.g. critical thresholds) that shall be used for routine monitoring. These analyses are based on the state of the art literature and on the specific experience of local experts. Every two years the national bodies convene a global review meeting (at UN level) in order to ensure cross-consistency and standardisation of the methodologies.

A similar system to the above mentioned conventions could be set up for a biomass potential assessment in Europe.

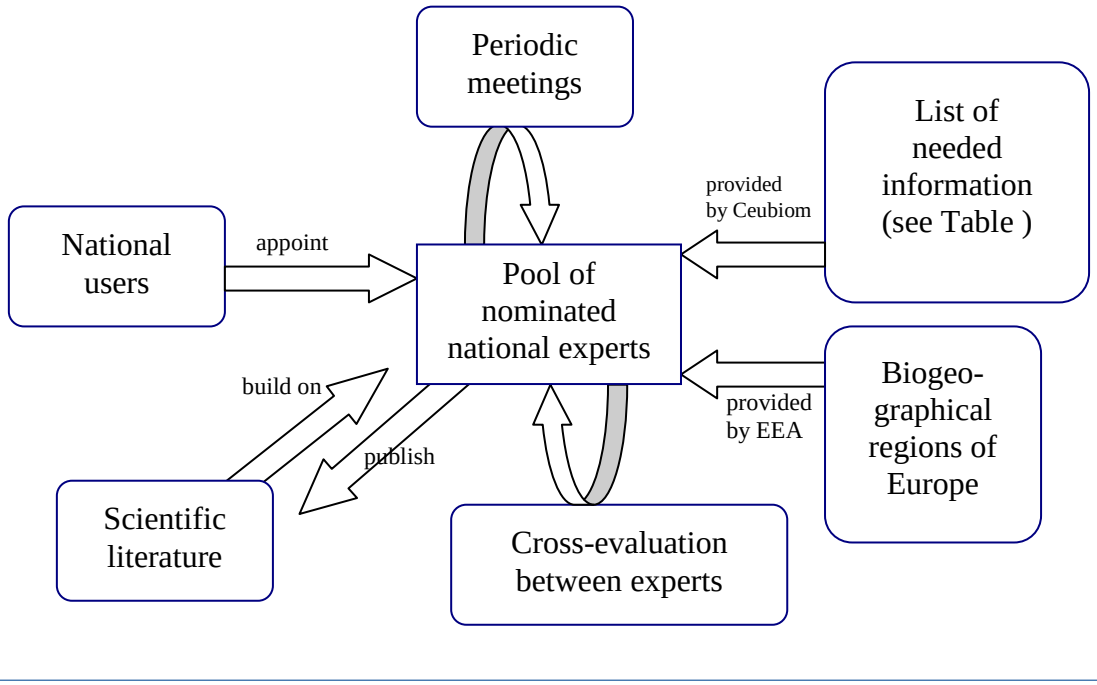


Figure 17: Quality assurance framework for local expert knowledge

The quality assurance framework includes

a) clear definition on what information the experts are requested to give (including units)
b) sundivision of Europe into biogeographical regions and
c) regular meetings and discussions (both physical meetings as well as web-based discussions)

ad a) clear definition of data needed

The input needed from local experts (LEK) is described in Table 9. Information on what each input means and how to use it in the approach are given in the respective chapters (e.g. Chapter 5.2 for forest biomass).

ad b) Subdivision of Europe into bio-geographic regions

Bio-geographic regions represent a broad concept which includes: vegetation (forests and meadows), flora and fauna, as well as terrestrial and aquatic ecosystems. This subdivision of Europe can help facilitate exchange between local experts from the same bio-geographical regions and can be used to fill knowledge gaps and harmonize the suggested local expert inputs across country borders.

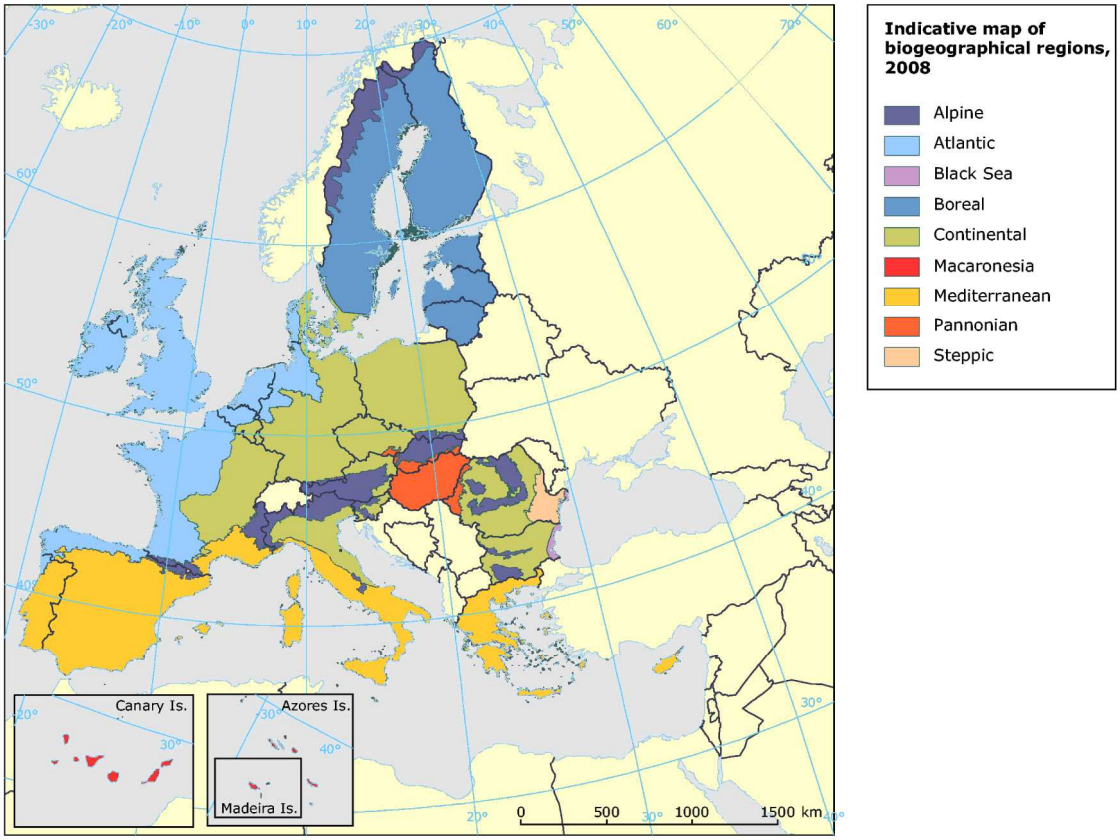


Figure 18: Biogeographical regions of Europe (source: EEA, http://www.eea.europa.eu/data-and-maps/figures/biogeographical-regions-europe-2005-with-national-boundaries)

This subdivision can also help by filling knowledge gaps. If no local expert knowledge is available for a certain region, then an expert from another area in the same bio-geographical region can give an indication on the values.

A shortcoming of this subdivision is that the currently available map does not include countries that are not EU members.

Another approach is the inclusion of a European forest region map (see Figure 20 from [Mayer, 1986]). The division of classes in the map shown is related to habitat characteristics (primarily climate) and provides a broad representation of forest species throughout Europe.

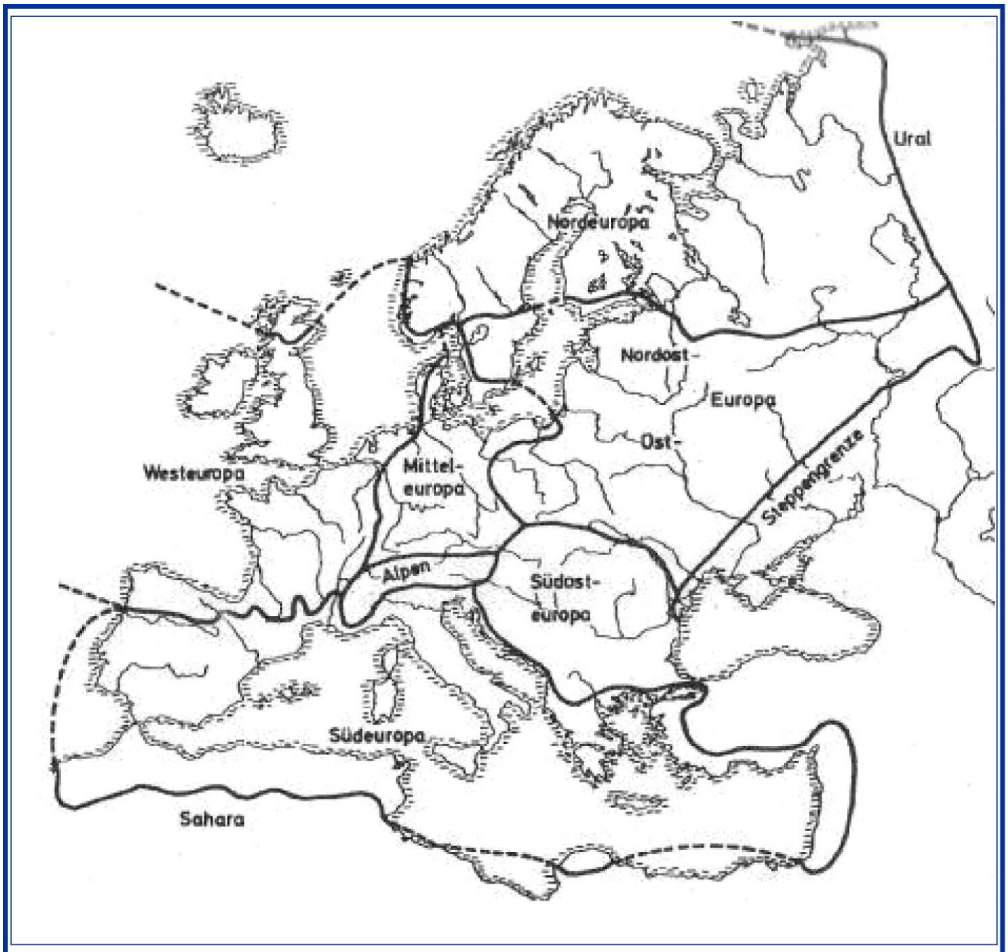


Figure 19: Forest regions in Europe [Mayer, 1986]

Ad c) regular meetings and discussions

Coordination between the appointed local experts should be implemented in order to sustain a common level of understanding and a common perspective on this sensitive issue. In order to improve harmonization and high quality information output from the local experts, two tools are suggested:

1. regular meetings of the nominated local experts to exchange experience and to 'calibrate' their outputs
   It is recommended to have periodic meetings of the nominated experts to compare the suggested values for the assessments in the different countries. Experts from different countries in the same bio-geographic region should form groups and discuss, consolidate values and explain differences. Both physical meetings and also web-based discussions should be used for this purpose. Physical meetings should preferably take place back-to-back with biomass conferences to save on travel budget.
2. cross-evaluation between local experts in order to assure a common view and high quality results.
   In addition to the meetings, the expert values and inputs should be sent to a second group of experts to cross-check the reliability of the data and thus to ensure the quality of the output.

It is clear, that this project can only suggest a quality assurance system. It is up to the European and national administrations to actually implement such a framework.

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Annex 1: NUTS regions of Europe

(Source: http://ec.europa.eu/eurostat/ramon/nuts/basicnuts_regions_en.html)

In several sections of this document, NUTS is mentioned for the spatial subdivision of Europe. The Nomenclature of Territorial Units for Statistics (NUTS) was established by EUROSTAT more than 30 years ago in order to provide a single uniform breakdown of territorial units for the production of regional statistics for the European Union. The NUTS nomenclature was created and developed according to the following principles:

a) The NUTS favors institutional breakdowns.

Different criteria may be used in subdividing national territory into regions. These are normally split between normative and analytic criteria:

- **normative regions** are the expression of a political will; their limits are fixed according to the tasks allocated to the territorial communities, according to the sizes of population necessary to carry out these tasks efficiently and economically, and according to historical, cultural and other factors;
- **analytical** (or functional) **regions** are defined according to analytical requirements; they group together zones using geographical criteria (e.g. altitude or type of soil) or using socio-economic criteria (e.g. homogeneity, complementarity or polarity of regional economies).

For practical reasons to do with data availability and the implementation of regional policies, the NUTS nomenclature is based primarily on the **institutional divisions** currently in force in the Member States (normative criteria).

b) The NUTS favors regional units of a general character.

Territorial units specific to certain fields of activity (mining regions, rail traffic regions, farming regions, labor-market regions, etc.) may sometimes be used in certain Member States. NUTS excludes specific territorial units and local units in favor of regional units of a general nature.

c) The NUTS is a three-level hierarchical classification

Since this is a hierarchical classification, the NUTS subdivides each Member State into a whole number of NUTS 1 regions, each of which is in turn subdivided into a whole number of NUTS 2 regions and so on. Some NUTS regions appear at several levels (example: Luxembourg appears as the country and at levels 1, 2 and 3). In this case, codes end in zero for the region with identical territory at the next lower level. The labels need not be identical at the different levels even if the territorial extent of the regions concerned is identical. At a more detailed level, there are the districts and municipalities. These are called 'Local Administrative Units' (LAU) and are not subject of the NUTS Regulation.

The NUTS Regulation lays down rules for future amendments of the regional breakdown used by the European Union. A first revision of the NUTS classification was scheduled for 2006, three years after the 2003 version. For the 10 new Member States, the same rule applies, i.e. amendments were possible in 2006. This means that, exceptionally, the moratorium before changes are allowed is only 2 years for the new Member States.

Annex 2: Definition of local expert knowledge input

Table 29: Definition of local expert knowledge input (all categories)

ID	Category	Input short	Explanation	Example
F1	Forestry	Weights for increment per parameter elevation, soil, species, density, forest management	These weights determine how much the different parameters influence the net annual increment of forest. The weights have to sum up to 1. No common unit definition applies.	Elevation: 0.2 Soil: 0.3 Density: 0.2 Forest management practice: 0.3
F2	Forestry	Weights for total growing stock per parameter elevation, soil, species, density, forest management	These weights determine the influence of the different parameters on the net annual increment of forest. The weights have to sum up to 1. Note that the values for F1 and F2 are probably similar, but can also be different (especially in terms of forest management). No common unit definition applies.	Elevation: 0.2 Soil: 0.3 Density: 0.2 Forest management practice: 0.3
F3	Forestry	Index value for NAI per class of each parameter between 0 and 1	Each parameter (see F1/F2) can be subdivided into meaningful classes. The number of classes is open. For each class, an index should be assigned between 0 (no growing) and 1 (best growing condition) for NAI. The sum of index values per parameter does not have to sum up to 1, it is open. No common unit definition applies.	Elevation > 600 m: 0.6 Elevation <= 600 m: 1 Soil type 1: 0.8 Soil type 2: 0.1 Soil type 3: 0.5 etc.
F4	Forestry	Index value for total growing stock per class of each parameter between 0 and 1	Same as F3, but for growing stock (can be similar or different) No common unit definition applies.	Same as F3, but for growing stock (can be similar or different)
F5	Forestry	Sustainability level of growing stock per pixel and zone	This value is the optimal growing stock per pixel for zone A (normal forest). This value can be calculated be downscaling an amount per ha to the pixel size (typically 20x20m = 400 m²). Unit: m³ over bark	Zone A (normal forest): 13,5 m³

F6	Forestry	Years to reach sustainability level in zone A	This value is used to calculate the annual amount of additionally available biomass from currently underused forests. Unit: years	Zone A: 15 years
F7	Forestry	Slope-related no-go areas	This value is the threshold in terms of steepness of slope, above which no harvesting can be done for soil stability and cost reasons. Units: percent to define the class	> 40 % no extraction
F8	Forestry	Soil-related reduced extraction	These thresholds define restrictions of biomass extraction based on the soil types. Unit: percent of allowed extraction	Very shallow soils: no extraction Shallow soils: only 40% extraction All other soils: 80% extraction
F9	Forestry	Zone-related reduced extraction	Thresholds for zones B and C → reduction already based on reduced amounts (F7, F8)	Zone B: no extraction (0%) Zone C: normal extraction (100%)
A1	Agriculture	Index values for DTM derived parameters: elevation, slope and aspect. Needed for each crop type on local/regional scale	Each parameter can be subdivided into meaningful classes. The number of classes is open. For each class, an index should be assigned between 0 (no growing) and 1 (best growing condition).The sum of index values per parameter does not have to sum up to 1. No common unit definition applies.	Index values from 0-1 for each parameter and each crop
A2	Agriculture	Index values for soil parameters: Needed for each crop type on local/regional scale	Each parameter can be subdivided into meaningful classes. The number of classes is open. For each class, an index should be assigned between 0 (no growing) and 1 (best growing condition).The sum of index values per parameter does not have to sum up to 1. No common unit definition applies.	Soil index between 0-1 for each crop
A3	Agriculture	Local product to residue ratio for each crop	Each crop is attributed a local product to residue ratio depending on the plant physiognomy, on the crop	e.g. 1/4 (one 4th is agricultural crop

			quality, on the amount of e.g. straw left on the field and other parameters.	product, 3/4th are residues)
A4	Agriculture	Conversion values for residue biomass to energy	The energy content for each residue (see separate list of residues) has to be evaluated. Average statistics exist in scientific literature, but values may differ significantly locally. One important issue is the water content of the biomass, which significantly reduces the energy content per ton of biomass.	Conversion value: e.g. kilojoules per ton of biomass for each residue at administrative level x (NUTS-x)
A5	Agriculture	Conversion values for crop biomass to energy	The energy content for each crop (=agricultural product) has to be evaluated. Average statistics exist in scientific literature, but values may differ significantly locally. One important issue is the water content in the biomass, which significantly reduces the energy content per ton of biomass.	Conversion value: e.g. kilojoules per ton of biomass for each crop at administrative level x (NUTS-x)
A6	Agriculture	Plant/tree density information	Plants per ha. Needed for estimating the biomass from permanent crops	Plants/trees per ha
A7	Agriculture	Amount of residues in tons per plant/tree	Residues per plant/tree in tons. Needed for estimating the biomass from permanent crops	Tons of biomass per plant or tree
A8	Agriculture	Soil-related reduced extraction	These thresholds define restrictions of biomass extraction based on the soil types. Unit: percent of allowed extraction	Very shallow soils: no extraction Shallow soils: only 40% extraction All other soils: 80% extraction
A9	Agriculture	Sustainability factor	The sustainability factor defines how much biomass from primary residues must remain on the field for soil fertilization and sustainable production. ATTENTION: In case this value is already considered in the product to residue ratio (A3) this value must not be used again.	Expressed as a weight or percentage: Example: 0.25 or 25% of residues must remain on the field
A10	Agriculture	Weights for production	These weights determine to what extent all additionally	Elevation: 0.2 Aspect: 0.1

		values for each parameter: elevation, aspect, slope, soil, …	used parameters influence the productivity of crop i at administrative level x. The weights must sum up to 1. No common unit definition applies.	Soil: 0.7 In this case the soil has the largest influence on productivity of crop i in region x.
G1	Grassland	Index values for DTM derived parameters: elevation, slope and aspect. Needed for each crop type on local/regional scale	Each parameter can be subdivided into meaningful classes. The number of classes is open. For each class, an index should be assigned between 0 (no growing) and 1 (best growing condition).The sum of index values per parameter does not have to sum up to 1. No common unit definition applies.	Index values from 0-1 for each parameter and each grassland type (in case more than one type of grassland is available)
G2	Grassland	Index values for soil parameters: Needed for each crop type on local/regional scale	Each parameter can be subdivided into meaningful classes. The number of classes is open. For each class, an index should be assigned between 0 (no growing) and 1 (best growing condition).The sum of index values per parameter does not have to sum up to 1. No common unit definition applies.	Soil index between 0-1 for each grassland type (in case more than one type of grassland is available)
G3	Grassland	Weights for production values for each parameter: elevation, aspect, slope, soil, …	These weights determine to what extent all additionally used parameters influence the productivity of grassland at administrative level x. The weights must sum up to 1. No common unit definition applies.	Elevation: 0.2 Aspect: 0.1 Soil: 0.7 In this case the soil has the largest influence on productivity of crop i in region x.
G4	Grassland	Availability index	Amount of grassland needed for fodder / available for energy use	25 % available for energy use
G5	Grassland	Conversion values for crop biomass to energy	The energy content for each grassland type (in case more than one type of grassland is available) has to be evaluated. Average statistics exist in scientific literature, but values may differ significantly locally. One	Conversion value: e.g. kilojoules per ton of biomass for each grassland type at administrative level x (NUTS-x)

			important issue is the water content in the biomass, which significantly reduces the energy content per ton of biomass.	

Annex 3: Optical data preprocessing

Pre-processing is the umbrella term for a variety of methods and processes, which are necessary to make the input data 'fit the purpose'. These steps are often not taken proper care of and their influence on the final results is very often strongly underestimated, especially when working with multi-temporal data and different information sources of different spatial resolutions. Only the main steps are given here with a short explanation and some important references. For further information the reader is referred to standard remote sensing literature, e.g. [Lillesand et al., 2008] or http://www.ccrs.nrcan.gc.ca/resource/tutor/fundam/chapter4/04_e.php.
In general preprocessing operations intend to correct for sensor- and platform-specific radiometric and geometric distortions of the data. Radiometric corrections are necessary due to variations in scene illumination and viewing geometry, atmospheric conditions, and sensor noise and response. All these effects vary in dependence of the specific sensor/platform and the respective conditions during data acquisition. When working with multi-temporal data for vegetation analysis it is crucial to calibrate the data to known (absolute) radiation or reflectance values.
During the geometric correction process the data are allocated to a spatial reference system. Geometric correction is normally needed for geo-coding the data to a reference system, or to eliminate geometric distortions within the data set, or to transform different datasets. In case of mountainous terrain a topographic normalization may be needed. Cloud and cloud-shadow masking as a final preprocessing step is often also needed.

Atmospheric Correction

Atmospheric influences often hamper the analysis of the image classification. Nowadays there is a variety of approaches available for the correction of these influences [Huang et al., 2008], [Wen et al., 2001]. In principle they can be subdivided in three different approaches:
1. *Normative methods*, whereby with the help of simple algorithms the pixel values are corrected based on the know behavior of the different spectral bands in regard to the reflection of respective earth objects. Known algorithms are, i.e. histogram-minimum or regression methods.
2. *Radiative transfer models*, model the exact atmospheric interactions. Most commonly known are the complex approaches of the LOWTRAN (Low Resolution Atmosperhic Radiance Transmittance), MODTRAN (Moderate Radiance Transmittance) and 5S-Code (Simulation of the Satellite Signal in the Solar Spectrum).
3. *Physically-based methods*, which actually rely on physical atmospheric data but do not model the interactions directly during the correction process. Instead they rely on lock-up tables and calculated standard atmospheres, i.e. ATCOR (Atmospheric and Topographic Correction for Rugged Terrain).

Geometric correction

The geometric correction is a two-fold process. In a first step it is necessary to collect ground control points in the reference and the 'to be corrected' data set. These can either be ground truth points from field visits or manually or automatically collected points within the images. In a second step the geometric transformation parameters are estimated and the transformation is calculated. For the adjustment of the pixels to their new location different resampling algorithms can be chosen, i.e. nearest neighbor, cubic convolution or bilinear.

Topographic normalization

Strong topography causes different illumination of the north- and south-facing slopes. This effect has to be corrected by normalization procedures in all areas with mountainous terrain. Topographic normalization is therefore often needed for areas with mountainous terrain and algorithms are provided in the scientific literature (see [Colby, 1991], [Meyer et al., 1993], [Riano et al., 2003], [Gallaun et al., 2007])

Annex 4: Stepwise guideline to generate basic remote sensing products for forestry (the GEOLAND2 approach)

This section is provided to give a guideline for generating 'GEOLAND2 – like' products for those regions, where these products are not available.

Input remote sensing data:

To be in line with the products from GEOLAND2, the preferred data set would be

- SPOT 4 or
- SPOT 5 or
- IRS multispectral satellite data.

Spot 4 data has a geometric resolution of 20 m; Spot 5 has 10 m and IRS bands green, red and NIR have 23 m and MIR has only 70 m. All data sets should be resampled to a common resolution of 20 m. The spectral bands covered by the two sensor types are summarized in the following table:

Table 30: Spectral properties of Spot4/5 and IRS

Band	Spot4/5 spectral range	IRS spectral range
B1 : green	0.50 - 0.59 µm	0.52 – 0.59 µm
B2 : red	0.61 - 0.68 µm	0.62 – 0.68 µm
B3 : near infrared	0.78 - 0.89 µm	0.77 – 0.86 µm
B4 : mid infrared (MIR)	1.58 - 1.75 µm	1.55 – 1.70 µm

Processing method:

The processing chain as applied in the Geoland2 mapping is described in the following section and depicted in Figure 20 (exemplarily for crown cover percentage calculation). All tools are available within the Joanneum Research in-house software package IMPACT. The descriptions are based on the Methods Compendium derived within the Geoland2 project ([Ahola et al., 2009]).

1) Prepare training data (VHR data such as aerial images, laserscanner (LiDAR) data, stereo data, VHR satellite data like GeoEye)

The classification is based on already available reference data (e.g. LUCAS) or newly acquired reference data. With the JR-IMPACT ground data collection tool, area frame sampling is performed by interpretation of systematically distributed sampling points for forest and non-forest. In the first step the reference points are used to relate the grey values of the high resolution image to the cover types forest and non-forest and statistical parameters are computed. For crown cover percentages, Laserscanner data or very high resolution aerial images can be used to generate the training data. An example for such a set of training samples is shown in Figure 21.

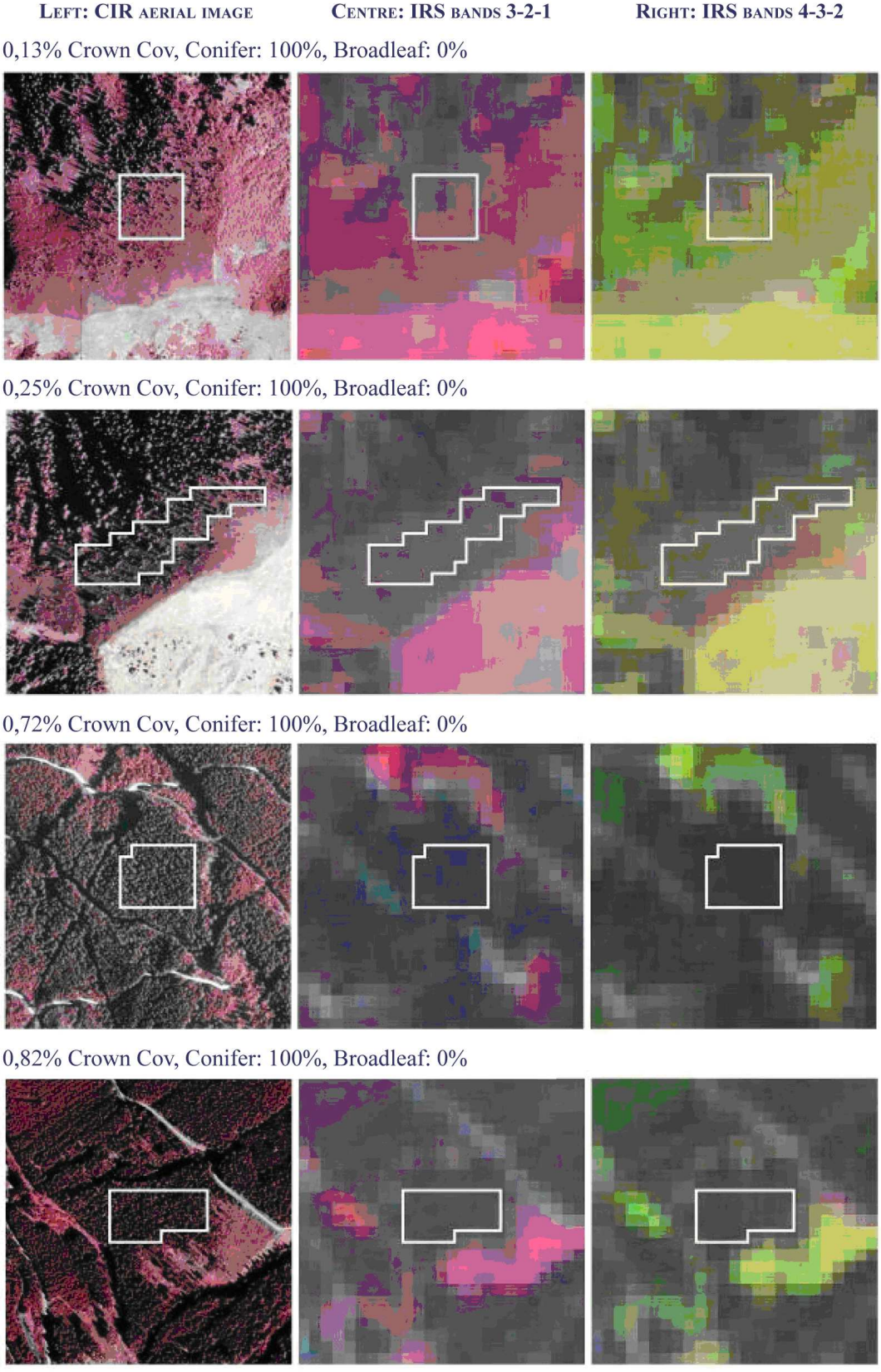

Figure 20: Set of training samples for crown cover percentages

Logistic regression is a variation of an ordinary regression which is used when the dependent (response) variable is a dichotomous variable and the independent (input) variables are continuous, categorical or both. Unlike the linear regression the relationship between the predictor and response variables is not a linear function in logistic regression.
The formula of the logistic regression model is given in Equation 11 below.

$$P(x) = \frac{e^{\eta}}{1+e^{\eta}} \quad with \quad \eta = \beta_0 + \beta_1 x_1 + ... + \beta_n x_n$$

Where

P … probability of occurrence of an event
β … regression coefficients
x … predictor variables

Equation 11: Logistic regression model

Multinomial logistic regression involves nominal response variables for more than two categories. Multinomial logit models are multi-equation models. A response variable with k categories will generate k-1 equations. Each of these k-1 equations is a binary logistic regression comparing a group with the reference group. Multinomial logistic regression simultaneously estimates the k-1 logits. Further, it is also the case, that the model tests all possible combinations among the k groups although it only displays coefficients for the k-1 comparisons.

2) Calculate linear regression coefficients

In this step the regression coefficients are computed by means of logistic regression. For calculation of the regression parameters the response vector and the predictor variables are required. The cover types of the reference data serve as response vector and the grey values of the reference data serve as predictor variables. Besides the regression coefficients the program delivers quality information about the regression coefficients.

3) Stratify

In this step the high resolution image is separated into strata by performing the multinomial regression. The regression delivers for each pixel a membership probability to one stratum.

4) Estimate computation per stratum

In this step for each stratum the respective linear regression for crown cover and/or proportion of conifers is performed. For each pixel the proportion of conifers and a crown cover value is generated.

5) Accuracy assessment by cross-validation

Accuracy Assessment is performed in the final step by cross validation. Using 95% of the reference data the regression coefficients are estimated repeatedly. With the derived regression coefficients the regressions are performed. The calculated values are compared with the given values of the reference data. With the residues statistical parameters are computed. By repeating parameter estimation and classification with other samples of the reference data cross validation is done.

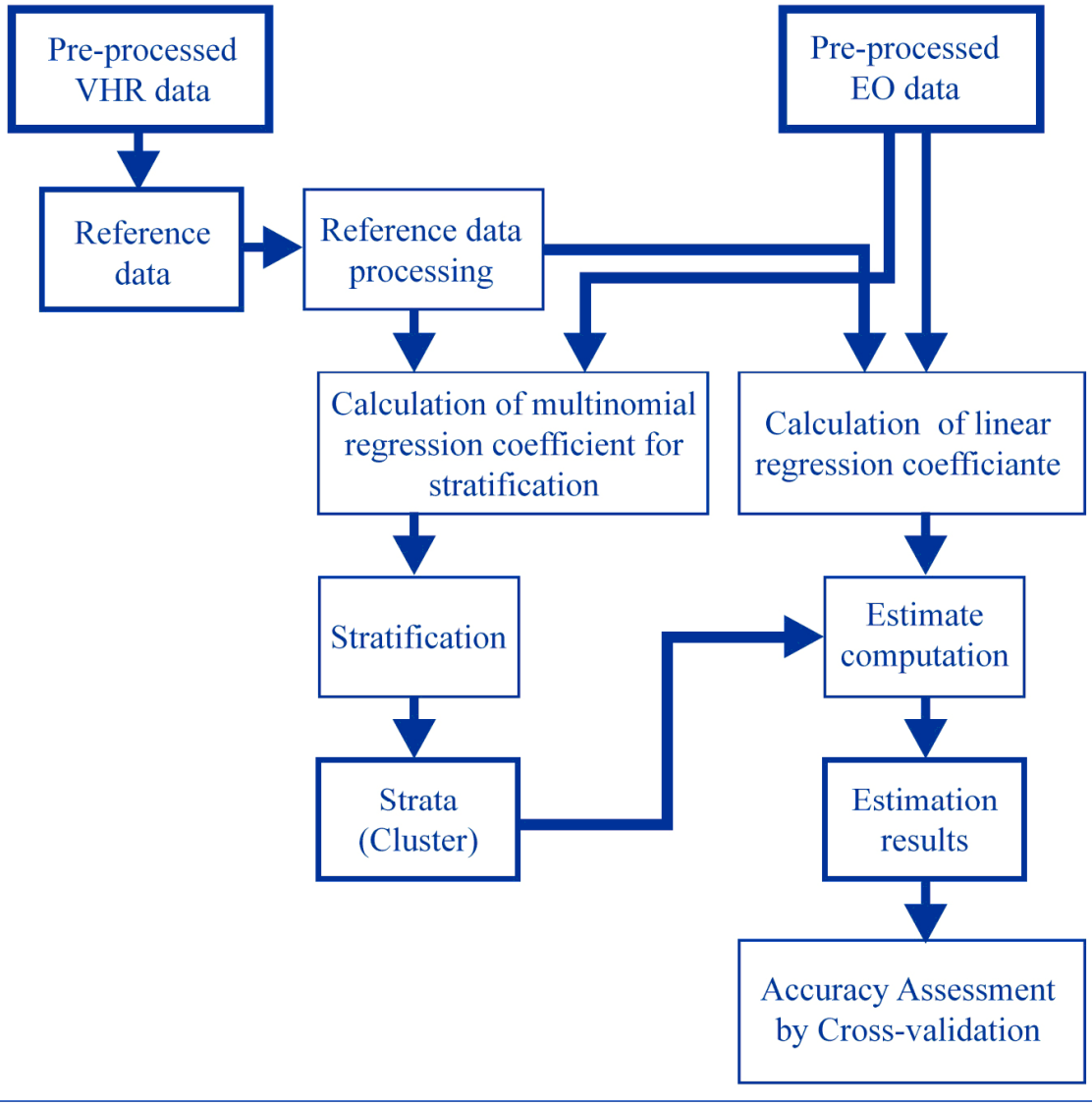

Figure 21: Processing chain to estimate continuous classes

Post-processing methods:

6) Apply your thresholds for the classes
   a. forest / non-forest (e.g. FAO definition: > 10% forest cover = forest)
   b. coniferous, deciduous, mixed
   c. density classes

Annex 5: Determination of the energy content of biomass

Biomass potential is in general given in mass units, usually of wet material. Biomass in practice contains water - sometimes up to 60 %. The water content influences the energy content substantially. In this section, the description of how to determine the energy content of biomass is given.

As a first illustration: Fresh wood is collected with a water content of ca. 50 %. So one kg of fresh wood consists of 50 % water and 50 % dry wood. So, if this fresh wood is combusted in practice, 0.5 kg of dry wood is combusted and 0.5 kg of water will be evaporated and emitted as steam together with the flue gases. The energy content of 1 kg of fresh wood will result of the energy content of 0.5 kg dry wood reduced by the energy consumption of evaporating 0.5 kg water.

For energy issues, usually the lower heating value (LHV, or net HV) is used. It describes the energy content of a fuel to be used after thermo-chemical conversion processes (combustion, gasification etc.). It means that the water generated in thermo-chemical conversion is not condensed, but is emitted as steam with the flue gas.

For the calculation of the heating value of wet biomass (LHV_{wet}) we need information on:

- LHV of dry biomass and (LHV_{dry})
- Water content w (water mass/mass of wet biomass)

In most of the data bases on energy contents, the LHV of water free biomass is given. There are several data basis available. One of the best and most reliable is http://www.vt.tuwien.ac.at/Biobib/biobib.html, tutored by the Vienna Technical University.

The water content of biomass in practice can be very different, e.g. straw can show water contents between 7 and 30 %, corn stalks from about 20 % to 50 %. It depends on several parameters (climate, soil quality, weather, daytime of harvest, harvest mode etc). The same situation can be observed with wood as a fuel. Fresh wood (tree felling) shows water contents from 40 to 60 %, fuel wood dried in the open air about 25 to 35 % water content, industry by-products from sawmills only have 5 to 10 % water content (shavings). The value therefore has to be determined by local experts that have experience with the local conditions.

The calculation of the heating value follows the relation:

$LHV_{wet} = LHV_{dry}*(1-w) – 2400*w$ in [kJ/kg]

(The evaporating heat of water is typically 2400 kJ/kg)

Annex 6: Calculation of Slope and Aspect

Slope (e.g. from [[Erdas, 2009], partly modified):

Slope is expressed as the change in elevation over a certain distance. Slope is most often expressed as a percentage, but can also be calculated in degrees.

First, the average elevation changes per unit of distance in the x and y direction (Δx and Δy) are calculated as:

$$\Delta x_1 = c - a \qquad \Delta y_1 = a - g$$
$$\Delta x_2 = f - d \qquad \Delta y_2 = b - h$$
$$\Delta x_3 = i - g \qquad \Delta y_3 = c - i$$

$$\Delta x = (\Delta x_1 + \Delta x_2 + \Delta x_3)/3 \times x_s$$

$$\Delta y = (\Delta y_1 + \Delta y_2 + \Delta y_3)/3 \times y_s$$

Where:

$a...i$ = elevation values of pixels in a 3 × 3 window, as shown above

x_s = x pixel size = 30 meters

y_s = y pixel size = 30 meters

The slope at pixel x,y is calculated as:

$$s = \frac{\sqrt{(\Delta x)^2 + (\Delta y)^2}}{2} \qquad s = 0.0967$$

$$\text{if } s \le 1 \qquad \text{percent slope} = s \times 100$$

$$\text{if } s > 1 \qquad \text{percent slope} = 200 - \frac{100}{s}$$

$$\text{slope in degrees} = \tan^{-1}(s) \times \frac{180}{\pi}$$

Equation 12: Calculation of slope

Aspect (e.g. from [Erdas, 2009], partly modified):

An aspect image is an image file that is gray scale coded according to the prevailing direction of the slope at each pixel. Aspect is expressed in degrees from north, clockwise, from 0 to 360. Due north is 0 degrees. A value of 90 degrees is due east, 180 degrees is due south, and 270 degrees is due west. A value of 361 degrees is used to identify flat surfaces such as water bodies.

$$\Delta x_1 = c - a \qquad \Delta y_1 = a - g$$
$$\Delta x_2 = f - d \qquad \Delta y_2 = b - h$$
$$\Delta x_3 = i - g \qquad \Delta y_3 = c - i$$

Where:

a...i = elevation values of pixels in a 3 × 3 window as shown above

$$\Delta x = (\Delta x_1 + \Delta x_2 + \Delta x_3)/3$$

$$\Delta y = (\Delta y_1 + \Delta y_2 + \Delta y_3)/3$$

If $\Delta x = 0$ and $\Delta y = 0$, then the aspect is flat (coded to 361 degrees).
Otherwise, θ is calculated as:

$$\theta = \tan^{-1}\left(\frac{\Delta x}{\Delta y}\right)$$

Equation 13: Calculation of aspect

Note that Θ is calculated in radians, in degrees, aspect is 180 + Θ.

Annex 7: Source data

Annex 7.1: Forestry data available for each considered 'CEUBIOM' country

Table 31: Last update of EUROSTAT and national (red) forest related terrestrial data available in the countries

Countries	Net annual increment/ last update	Annual fellings/ last update	Fuelwood production coniferous / non-coniferous last update	Roundwood production coniferous / non-coniferous last update	Fuelwood imports/ last update	Fuelwood exports/ last update	Roundwood coniferous /non-coniferous imports/ last update	Roundwood coniferous /non-coniferous exports/ last update
Austria	2000	2000	2008	2008	2008	2008	2008	2008
BiH	Will be available 2010/2011	2009	2009	2009	N/A	N/A	N/A	N/A
Bulgaria	2005	2005	2008	2008	2008	2008	2008	2008
Croatia	2008	2008	2008	2008	2008	2008	2008	2008
Czech Republic	2005	2005	2008	2008	2008	2008	2008	2008
Germany	2005	2005	2004	2004	2008	2008	2008	2008
Greece	2005	2005	1989	1989	2008	2008	2008	2008
Hungary	2005	2005	2008	2008	2008	2008	2008	2008
Italy	2005	2005	2008	2008	2008	2008	2008	2008
FYROM	1979	2008	2008	2008	2008	2008	2008	2008
Poland	2005	2005	2008 (e)	2008	2008	2008	2008	2008
Romania	2005	2005	2008	2008	2008 (p)	2008 (p)	2008 (p)	2008 (p)
Slovakia	2005	2005	2008	2008	2008	2008	2008	2008
Slovenia	2005	2005	2008	2008	2008	2008	2008	2008
Ukraine	2009	2009	2009 (wood in total)		2010 (wood in total, no differentiation into fuelwood/roundwood, coniferous/ non-coniferous)			

(e) estimates, (p) provisional values

The sources for these statistics are as follows:

- BiH: Federal Office of Statistics (FZS) www.fzs.ba; Republika Srpska Institute of Statistics www.rzs.rs.ba; Agency for Statistics of Bosnia and Herzegovina (BHAS) www.bhas.ba

- Croatia: All this refers to state owned forests (about 75% of Croatia's forests) by Hrvatske Šume (Croatian Forests: http://portal.hrsume.hr/index.php/en/forests/general/forests-in-croatia). Private forests mapping is ongoing by Šumska savjedotavna služba (Forestry advisory service: http://suma-ss.hr/forest-extension-service-for-private-forests-in-croatia.html); results are expected by 2015
- Czech Republic: http://www.czso.cz/csu/2009edicniplan.nsf/kapitola/0001-09-2009-1500 and http://eagri.cz/public/eagri/file/3868/_2201091k15_1_.pdf
- Germany:http://www.destatis.de/jetspeed/portal/cms/Sites/destatis/Internet/DE/Content/Publikationen/Fachveroeffentlichungen/UmweltoekonomischeGesamtrechnungen/Waldgesamtrechnungen__1993,property=file.pdf
- Greece: [Eleftheriadis, 1986], [Greek Ministry of Food and Agriculture, 2005]
- FYROM: www.stat.gov.mk
- Ukraine: http://www.ukrstat.gov.ua/operativ/operativ2010/zd/e_iovt/03_2010/9.rar

Table 32: NFI and FMP data availability in the countries

Countries	NFI existing/ last update	FMP existing/ last update	Comments/sources:
Austria	Yes/2002 Update 2007/2009	Yes/2008	http://www.walddialog.at/filemanager/download/46297/Austrian%20Forest%20Report%202008/1
Bosnia and Herzegovina	Will be in 2010/2011	Yes/ continuous	Not yet available
Bulgaria	Yes/2005	Yes/2006	http://www.icp-forests.org/pdf/NatRepBulgaria2005.pdf http://www.un.org/esa/forests/pdf/national_reports/Bulgaria.pdf
Croatia	Yes/2008	Yes/2008	http://portal.hrsume.hr/index.php/hr/ume/opcenito/sumeuhrv http://suma-ss.hr/forest-extension-service-for-private-forests-in-croatia.html
Czech Republic	Yes/2004	Yes/2001	http://www.uhul.cz/il/vysledky/index.php http://www.bfn.de/fileadmin/MDB/documents/skript51.pdf
Germany	Yes/2002	Yes/2001	http://www.bundeswaldinventur.de/enid/c483a70c6f8e97cf7f9e7b4afee51e59,51519f6d6f6465092d09/2.html http://www.bfn.de/fileadmin/MDB/documents/skript51.pdf
Greece	Yes/1992	(yes)*	Can be obtained at request from the General Secretary of Forestry. Ministry of Agriculture
Hungary	Yes/ continuous	Yes/continuous	http://www.mgszh.gov.hu/en/ http://www.mgszh.gov.hu/en/
Italy	Yes/2005	Yes/continuous (2007 – 2013)	http://www.sian.it/inventarioforestale/jsp/documentazione.jsp http://www.reterurale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/2826
FYROM	Yes/1979	Yes/ continuous	http://www.mzsv.gov.mk/ www.mkdsumi.com.mk
Poland	Yes/ continuous	Yes/ continuous	available in Regional Boards of National Forests (78% of all Polish forests) the time of each update is also available
Romania	Yes/1984 – next in 2012	Yes/2010	http://www.madr.ro/pages/paduri/raport-starea-padurilor-2007.html http://www.madr.ro/pages/page.php?self=02&sub=0202&tz=020201
Slovakia	Yes/2005-2006	Yes/2009	www.nlcsk.sk
Slovenia	Yes/2007	Yes/2009	http://www.gozdis.si/ http://dklg.kmu.gov.ua/forest/control/en/publish/article?art_id=36410&cat_id=33924
Ukraine	Yes/2008	Yes/2009	http://dklg.kmu.gov.ua/forest/control/uk/publish/article?art_id=62921&cat_id=32867 http://dklg.kmu.gov.ua/forest/control/en/publish/article?art_id=36410&cat_id=33924

(*) Strategic forestry plan at national level planned, but never implemented (Forest Research Institute, 1986)

The term ‘continuous’ means that there is continuous updating within the area. Each year another part of the region is done leading to a general updating cycle of 10 years (mostly). The year of the last update is thus different for each sub-region, but can generally be obtained from the same source

Table 33: National availability of BEFs

Country	Source
Austria	http://www.umweltbundesamt.at/fileadmin/site/publikationen/M106.pdf
Bosnia and Herzegowina	[Matic et al., 1980]
Bulgaria	http://timber.unece.org/fileadmin/DAM/publications/EFISCENDataSources_19112009.xls
Croatia	http://portal.hrsume.hr/index.php/hr/ume/opcenito/sumeuhrv
Czech Republic	N/A
Germany	2007 Schulze, A.; Meiwes, K.J.; Kernbach, M.; Nagel, J. Biomasse-Expansionsfaktoren. Abschlussbericht zum Forest Focus C2-Projekt Nr. 5, DE 2003-2004 NI, 33 S.
Greece	N/A
Hungary	http://www.mgszh.gov.hu/szakteruletek/szakteruletek/erdeszeti_igazgatosag/erdovagyon_adatok/szak_koz/adatok
Italy	http://www.apat.gov.it/site/_contentfiles/00158100/158102_rapporto_113_2010.pdf
FYROM	N/A
Poland	http://www.idpan.poznan.pl/index.php/pracownie/216-pracownia-bioindykacji.html http://www.au.poznan.pl/kul/english.html
Romania	Soon available (end 2011) from http://www.madr.ro/pages/page.php?self=02&sub=0202&tz=020201
Slovakia	N/A
Slovenia	N/A
Ukraine	N/A

Annex 7.2: Agricultural data available for each considered 'CEUBIOM' country

Table 34: NUTS-3 level statistics or equivalent spatial resolution (from national data centres)

NUTS-3 or equivalent (from national data)	Cere-als (with rice)	Cereals (without rice)	wheat	rye	barley	Grain maize	rice	Dried pulses	potatoes	Sugar beet	Oil seeds	rape	Sunflower seed	Oil flax	Fruit trees	vineyards	Total olives
Austria	P2009	P2009	P2009	P2009	P2009	P2009	P2009	P2009	P2009	P2009	P2009	P09	P2009	P2009	P2007	P2009	N/E
Bosnia-Herzegovina	N/E	N/A	N/A	N/A	N/A	N/A	N/E	N/A	N/A	N/A	N/A	N/A	N/A	N/E	N/A	N/A	N/A
Bulgaria	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Croatia	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Czech Republic	-	YES	YES	YES	YES	YES	N/E	YES	YES	YES	YES	YES	YES	YES	Apples only	YES	N/E
Germany	-	YES +	YES +	YES+	YES+	YES+	N/E	N/A	YES+	YES+	N/A	YES +	N/A	N/A	N/A	N/A	N/E
Greece	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Hungary	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008
Italy	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009	2009
FYROM																	
Poland	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Romania	2008	2008	2008	2008	2008	2008	2008	2008*	2008	2008	2008*	2008	2008	2008	2008	2008	N/E
Slovakia	2008?	2008?	2008?	2008?	2008?	2008?	N/E	2008?	2008?	2008?	2008?	2008 ?	2008?	2008?	2008?	2008?	N/E
Slovenia	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Ukraine	YES	N/A	N/A	N/A	N/A	N/A	N/A	N/A	YES	YES	N/A	N/A	YES	N/A	N/A	N/A	N/A

N/A = data not available
N/E = data not existing (= no such crop existing)
YES = data exists but year unknown
* = yield data only partly available or not available
+ = no production statistics available, but land use area and yields
YEAR? = NUTS-3 data existing for this year, but unknown which crop types
P200x => P= possible 200x = year; NUTS-3 data not computed on a standard basis, but can be delivered on special request. Higher resolution data is available directly.

Table 35: NUTS-2 level statistics (available from EUROSTAT)

NUTS-2 level	Cere-als (with rice)	Cereals (without rice)	wheat	rye	barley	Grain maize	rice	Dried pulses	potatoes	Sugar beet	Oil seeds	rape	Sunflower seed	Oil flax	Fruit trees	vineyards	Total olives
Austria	2008	2008	2008	2008	2008	2008	2007*	2008	2008	2008	2008	2008	2008	2007*	2008	2008	2007
Bosnia-Herzegovina	N/E	N/A	N/A	N/A	N/A	N/A	N/E	N/A	N/A	N/A	N/A	N/A	N/A	N/E	N/A	N/A	N/A
Bulgaria	2007	2007	2007	2007	2007	2007	2007*	N/A	N/A	N/A	2007	2007	2007	2007*	N/A	N/A	2007
Croatia	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Czech Republic	2008	2008	2008	2008	2008	2008	N/E	2008	2008	2008	2008	2008	2008	2008	2008	2008	N/E
Germany	2003P	2003P	2003P	2003P	2003P	2003P	N/E	N/A	2003P	2003P	N/A	03P	2003P	N/A	2003P	2003P	N/E
Greece	2003	2003	2003	2003*	2003	2003*	2003*	2003	2003	2003*	2003*	2003	2003	N/A	2003	2003	2003
Hungary	2008	2008	2008	2008	2008	2008	2008*	2008	2008	2008	2008	2008	2008	2008	2008	2008	N/E
Italy	2007	2007	2007	2007*	2007	2007	2007*	2007*	2007	2007*	2007	07*	2007*	2007	2007	2007	2007
FYROM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Poland	2007	2007	2007	2007	2007	2007	N/E	2007	2007	2007	2007	2007	2007	2007	2007	2007	N/E
Romania	2008	2008	2008	2008	2008	2008	2008P	2008	2008	2008P	2008	2008	2008P	2008P	2008	2008	N/E
Slovakia	2008	2008	2008	2008	2008	2008	N/E	2008	2008	2008P	2008	2008	2008	2008P	2008	2008	N/E
Slovenia	2007	2007	2007	2007	2007	2007	N/E	N/A	N/A	N/A	N/A	2007	2007	2007	N/A	2007#	2007#
Ukraine	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A = data not available through EUROSTAT
N/E = data not existing (no such crop existing)
* = yield data only partly available or not available
P = all data only partly available (crop might not be relevant for some regions)
# = only land use statistics available

Table 36: NUTS-1 level statistics (available from EUROSTAT)

NUTS-1 level	Cere-als (with rice)	Cereals (without rice)	wheat	rye	barley	Grain maize	rice	Dried pulses	potatoes	Sugar beet	Oil seeds	rape	Sunflower seed	Oil flax	Fruit trees	vineyards	Total olives
Austria	2008	2008	2008	2008	2008	2008	2007*	2008	2008	2008	2008	2008	2008	2007*	2008	2008	2007
Bosnia-Herzegovina	N/E	N/A	N/A	N/A	N/A	N/A	N/E	N/A	N/A	N/A	N/A	N/A	N/A	N/E	N/A	N/A	N/A
Bulgaria	2007	2007	2007	2007	2007	2007	2007*	N/A	N/A	N/A	2007	2007	2007	2007*	N/A	N/A	2007
Croatia	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Czech Republic	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Germany	2008	2008	2008P	2008	2008	2008	N/E	N/A	2008	2008	N/A	2008	2003P	N/A	2008*	2008*	N/E
Greece	2003	2003	2003	2003*	2003	2003*	2003*	2003	2003	2003*	2003*	2003	2003	N/A	2003	2003	2003
Hungary	2008	2008	2008	2008	2008	2008	2008*	2008	2008	2008	2008	2008	2008	2008	2008	2008	N/E
Italy	2007	2007	2007	2007*	2007	2007	2007*	2007*	2007	2007*	2007	07*	2007*	2007	2007	2007	2007
FYROM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Poland	2007	2007	2007	2007	2007	2007	N/E	2007	2007	2007	2007	2007	2007	2007	2007	2007	N/E
Romania	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008P	2008P	2008	2008	N/E
Slovakia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Slovenia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ukraine	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A = data not available through EUROSTAT
N/E = data not existing (no such crop existing)
* = yield data only partly available or not available
P = all data only partly available (might not be relevant for some regions)
- = no NUTS-1 region defined for this country (or is the same as national data)

Table 37: National statistics (available from EUROSTAT)

EUROSTAT National level	Cere-als (with rice)	Cereals (without rice)	wheat	rye	barley	Grain maize	rice	Dried pulses	potatoes	Sugar beet	Oil seeds	rape	Sunflower seed	Oil flax	Fruit trees	vineyards	Total olives
Austria	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2007
Bosnia-Herzegovina	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Bulgaria	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007*	2007	2007	2007*
Croatia	2003	2003	2003	2003	2003	2003	N/E	2003	2003	2003	2003	2003	N/A	N/A	N/A	N/A	N/A
Czech Republic	2008	2008	2008	2008	2008	2008	N/E	2008	2008	2008	2008	2008	2008	2008	2008	2008	N/E
Germany	2008	2008	2008	2008	2008	2008	N/E	N/A	2008	2008	N/A	2008	2003	2008*	2008	2008	N/E
Greece	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	2003	03*	2003	N/A	2003	2003	2003
Hungary	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	N/E
Italy	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007	2007*	2007	2007	2007*
FYROM	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Poland	2007	2007	2007	2007	2007	2007	N/E	2007	2007	2007	2007	2007	2007	2007	2007	2007	N/E
Romania	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008	N/E
Slovakia	2008	2008	2008	2008	2008	2008	N/E	2008	2008	2008P	2008	2008	2008	2008	2008	2008	N/E
Slovenia	2007	2007	2007	2007	2007	2007	N/A	2007	2007	2006	2007	2007	2007	2007	2007	2007	2007
Ukraine	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A

N/A = data not available through EUROSTAT
N/E = data not existing (no such crop existing)
* = yield data only partly available or not available
P = all data only partly available (might not be relevant for some regions)
# = only land use statistics available

Table 38: National statistics (from national data centres for NON-EU countries)

National level from national data centers	Cere-als (with rice)	Cereals (without rice)	wheat	rye	barley	Grain maize	rice	Dried pulses	potatoes	Sugar beet	Oil seeds	rape	Sunflower seed	Oil flax	Fruit trees	vineyards	Total olives
Bosnia-Herzegovina	N/A	YES	YES	YES	YES	YES	N/A	YES	YES	YES	YES	YES	YES	N/A	YES	YES	YES
FYROM	?	?	YES	YES	YES	YES	YES	?	?	YES	?	?	?	?	?	?	?
Ukraine	2009	2008	2008	2008	2008	2008	2008	2009	2008	2008	N/A	2008	2009	2008	2008	2008	N/A
Croatia	2008	2008	2008	2008	2008	2008	N/A	2008	2008	2008	2008	2008	2008	2008	2008	2008	2008

YES = data existing (year unknown)
N/A = data not available

Table 39: Grassland statistics available through EUROSTAT

Grassland	national	NUTS-1	NUTS-2
Austria	2008	2008	2008
Bosnia-Herzegovina	YES *	-	-
Bulgaria	2007	N/A	N/A
Croatia	YES *	-	-
Czech Republic	2008	2008	2008
Germany	2008	2008	2003
Greece	2003	N/A	N/A
Hungary	2008	2008	2008
Italy	2007	2007	2007
FYROM	YES *	-	-
Poland	2007	2007	2007
Romania	2008	2008	2008
Slovakia	2008	N/E	2008
Slovenia	2007	N/E	2007
Ukraine	-	-	-

Table 40: Websites and contact persons to obtain agricultural data through national data centers:

Country	Organisation	Website	Contact person/details
Austria	Statistik Austria	www.statistik.at	Mag. Renate Bader BUNDESANSTALT STATISTIK ÖSTERREICH Direktion Raumwirtschaft Land- und Forstwirtschaft Guglgasse 13 1110 Wien Tel.: +43 (1) 711 28-7253 Fax: +43 (1) 493 43 00 E-Mail: renate.bader@statistik.gv.at
Bosnia-Herzegovina	N/A	N/A	N/A
Bulgaria	Ministry of Agriculture	N/A	N/A
Croatia	National Statistics Department	http://www.dzs.hr/default_e.htm	N/A
Czech Republic	Czech Statistical Office	(Regional Statistical Yearbooks), http://www.czso.cz/eng/redakce.nsf/i/regional_yearbooks	N/A
Germany	Regionalstatistik ?	https://www.regionalstatistik.de/genesis/online/online;jsessionid=F6603137256BDB0CD938449CF91905AA?operation=abruftabelleAbrufen&levelindex=1&levelid=1274103529129&index=4 https://www.regionalstatistik.de/genesis/online/online;jsessionid=F6603137256BDB0CD938449CF91905AA?operation=abruftabelleAbrufen&levelindex=1&levelid=1274104124136&index=8	N/A
Greece	N/A	http://www.statistics.gr/portal/page/portal/ESYE/PAGE-database	N/A
Hungary	N/A	N/A	N/A
Italy	N/A	N/A	N/A
FYROM	N/A	N/A	N/A
Poland	N/A	N/A	N/A
Romania	N/A	https://statistici.insse.ro/shop/?page=tempo1&lang=en	N/A

Slovakia	N/A	http://portal.statistics.sk/ regional: http://portal.statistics.sk/showdoc.do?docid=3159	N/A
Slovenia	N/A		N/A
Ukraine	N/A	http://www.ukrstat.gov.ua/	N/A

N/A = data contact details provided by the partner countries