CEUBIOM

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

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CEUBIOM APPROACH TO A HARMONISED METHODOLOGY

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SEVENTH FRAMEWORK
PROGRAMME

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Preface

This document contains selected parts of Deliverable 4.3 of the CEUBIOM FP7 project with an overview of the proposed approach towards a harmonised assessment of biomass for bioenergy. The purpose of this document is to collect user feedback that can be integrated into D4.3 before it is released.

To facilitate the information feedback, we have created a Feedback Form annexed to this document and downloadable from www.ceubiom.org/feedback.

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."*[2] 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.

The need for harmonising biomass assessments has been articulated by the professional community for years with the claims that *"there are no standard measuring and accounting procedures for biomass, so it is often impossible to make comparisons between sets of existing data…."*[3] The urgency to harmonise biomass resource assessment has also been addressed on a political level following the launch of the Biomass Action Plan as the *"first, coordinating step"* which established specific targets and a comprehensive framework for accelerating the deployment of biomass for electricity, heating and transport purposes.[4] 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 harmonised scheme at this stage."*[5] These factors have made long-term planning for the sustainable use of Europe's bioenergy resources a great challenge.

An almost infinite number of combinations exist for assessing biomass resources if one considers the various types of approaches, the different methodologies and the broad array of purposes of biomass assessment,. In their report, the BEE Consortium[6] compiled a database of about 250 types of assessment, out of which they selected 28 for detailed comparison[7]. There is an apparent need for harmonisation and the establishment of a common framework.

On the other hand, there is a legitimate 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 assessment 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 (which can be very specific for a particular type of biomass/residue after 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.

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[1] Classification of European Biomass Potential for Bioenergy Using Terrestrial and Earth Observations (CEUBIOM). Grant Agreement No 213634

[2] European Commission C(2007)560 of 26.02.07. FP7 WORK PROGRAMME 2007 Call for Proposals. Topic ENERGY.2007.3.7.1: Harmonisation of biomass resource assessment

[3] Rosillo-Calle (2007). "The Biomass Assessment Handbook.". Edited By Frank Rosillo-Calle, Sarah Hemstock, Peter de Groot and Jeremy Woods

[4] Biomass action plan {SEC(2005) 1573} Communication from the Commission - Biomass action plan {SEC(2005) 1573} /* COM/2005/0628 final */

[5] Brussels, 25.2.2010 COM(2010)11 final REPORT FROM THE COMMISSION TO THE COUNCIL AND THE EUROPEAN PARLIAMENT on sustainability requirements for the use of solid and gaseous biomass sources in electricity, heating and cooling SEC(2010) 65 final

[6] Biomass Energy Europe (FP7 Grant Agreement No. 213417, http://www.eu-bee.com/)

[7] BEE Project. Methods & Data Sources for Biomass Resource Assessments for Energy Version 2

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 impractical, counterproductive and most likely impossible to create. The market players should be able to decide what kind of assessments they require depending on their particular needs and specific boundary conditions. The same applies for academic and industrial research. There should always be space 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 (to 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, 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 at a European level; it is due to this that 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-bottom assessments on a European level[8]. 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 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 methods for how these national assessments are to be carried out is imperative because the issue of availability of biomass is *"considered important by almost all members"*[9].

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 a 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 the European level, thus allowing for a much more accurate comparison between the Member States and 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

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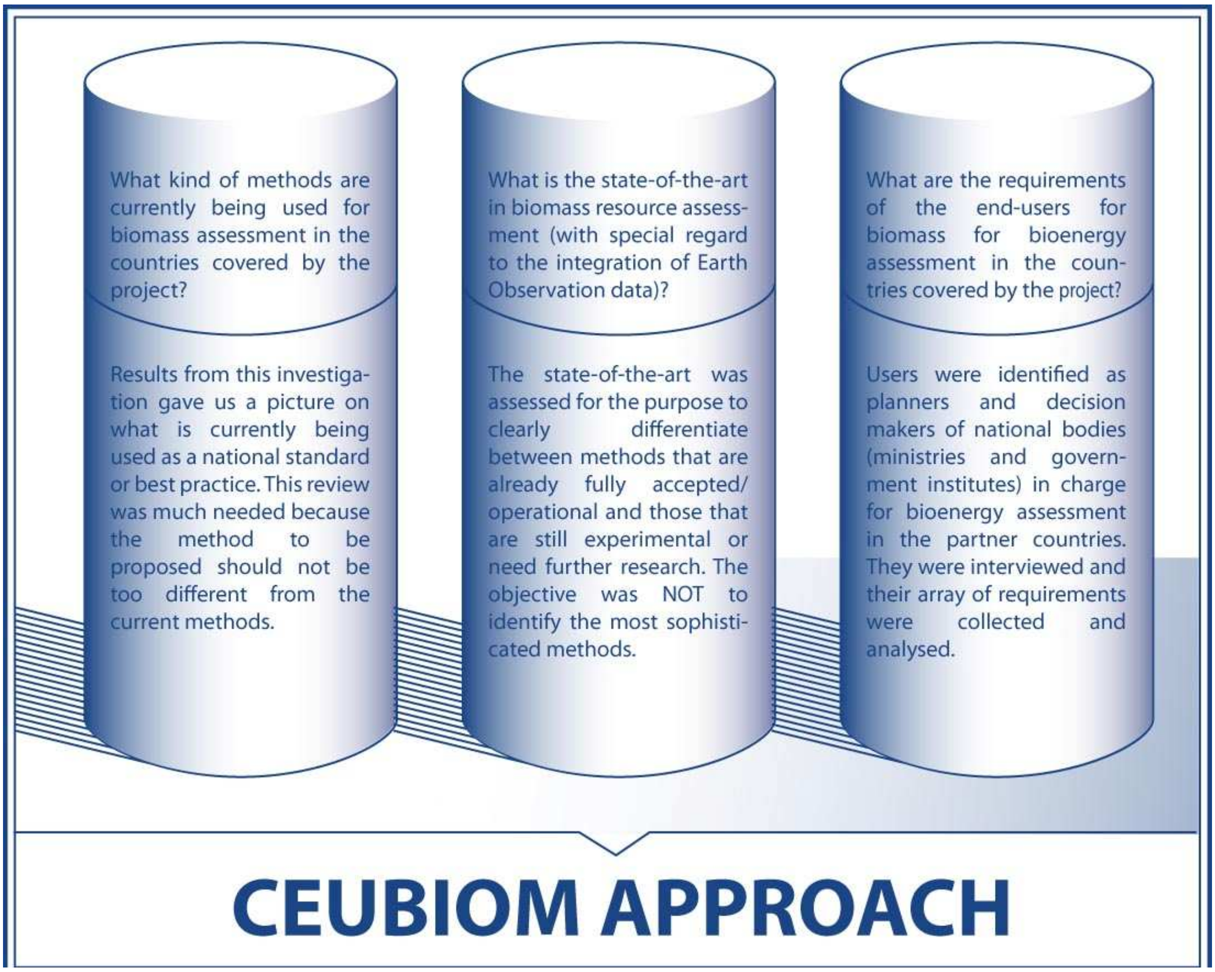
[8] For example EEA (2006). How much bioenergy can Europe produce without harming the environment? European Environment Agency. (2007) Environmentally compatible bio-energy potential from European forests, European Environment Agency (EEA)

[9] Third Meeting on National Biomass Actions Plans, Minutes of the Meeting, Brussels, 6 February 2008 http://europa.eu.int/comm/energy/res/biomass_action_plan/index_en.htm

where the ultimate goal was to propose a specific core method as opposed to simply reviewing the various possibilities.



What kind of methods are currently being used for biomass assessment in the countries covered by the project?

Results from this investigation gave us a picture on what is currently being used as a national standard or best practice. This review was much needed because the method to be proposed should not be too different from the current methods.

What is the state-of-the-art in biomass resource assessment (with special regard to the integration of Earth Observation data)?

The state-of-the-art was assessed for the purpose to clearly differentiate between methods that are already fully accepted/operational and those that are still experimental or need further research. The objective was NOT to identify the most sophisticated methods.

What are the requirements of the end-users for biomass for bioenergy assessment in the countries covered by the project?

Users were identified as planners and decision makers of national bodies (ministries and government institutes) in charge for bioenergy assessment in the partner countries. They were interviewed and their array of requirements were collected and analysed.

CEUBIOM APPROACH

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 as 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, harmonised manner across Europe, allowing for an easy aggregation of this data to European level and thus directly supporting relevant decision and policy making processes

- 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 environmental, technological, legal, social, economic, etc constraints that otherwise would be very specific to a particular country or region.

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

In terms of terminology CEUBIOM has generally adopted FAO’ Unified Bioenergy Terminology[10] and definitions[11]. Whenever a different term is used, or there are ambiguities about one, it is always indicated in all CEUBIOM documents and reports.

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[10] FAO (2004). UBET - Unified bioenergy terminology. Wood Energy Programme, Food and Agriculture Organization of the United Nations

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

2. Objectives and 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. Special emphasis was placed on the 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, 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 well 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 far more accurate, 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 countries covered by CEUBIOM. 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 mainly the Ministries of Agriculture, Forestry, Environment, Energy and of the Economy. In terms of national bodies and agencies, examples could include environment agencies or energy agencies.

During the course of the project end-user requirements were duly assessed (see CEUBIOM Deliverable 4.1[12]). The main requirements are summarised as follows:

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.

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

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 countries covered by CEUBIOM. 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) were needed to generate a useful result. Such frame conditions are generally 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 rapid changes and speculative prognosis, which should be avoided in order to providing users with accurate information of the potential assessment.

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 harmonised 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 is, however, 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 would be insufficient 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. The CEUBIOM approach

Terrestrial methods such as statistical surveys, ground measurements and questionnaires are frequently used to derive bioenergy potentials on different scales. 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 cannot 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 connected regions, which could lead to biased results.

Remote sensing systems are currently being used extensively 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 such a system. The main advantage of remote sensing is that it provides a very cost efficient way to collect the required information at areas which 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: less 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 2. 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.

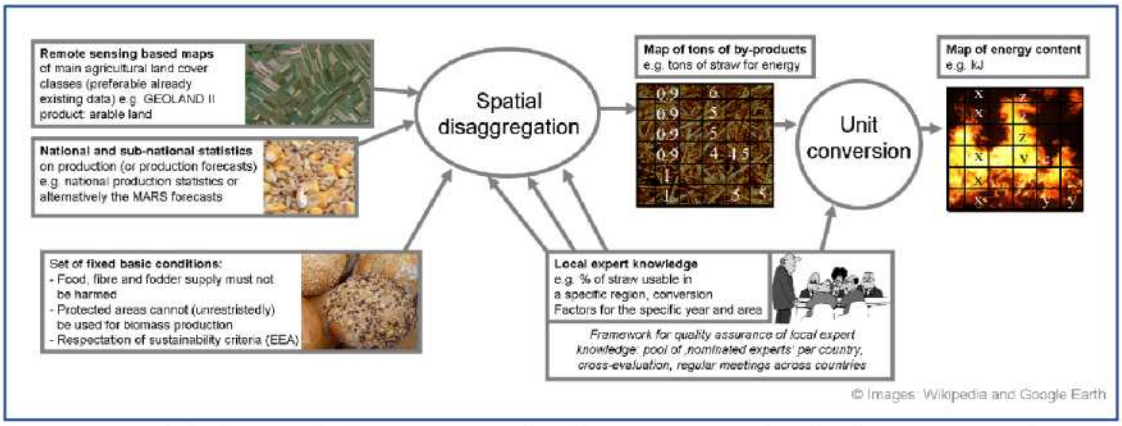

Figure 2: Simplified approach of using terrestrial and remote sensing data for biomass potential assessment for energy.

As already explained before, the following two approaches are described:

- A **Basic Approach** and
- an **Advanced Approach**.

The **basic approach** is designed in order to fulfil most of the user requirements given in Deliverable 4.1. This implies a rather small role of remote sensing techniques, because the users require a method which is similar to their known procedures; additionally,they often do not have the capacity to carry out 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 (available from operational services) 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 are described in the following:

- **spatial dimension**: Through the land cover maps, the potential can be geo-located and thus enabling 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.
- **applicable** to all countries in Europe: The approach relies on existing information and thus it was secured, that all needed input data are available or can be substituted.

The main drawbacks of the basic approach are oddly also related to the advantages. For 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 often 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 has also been developed.

The **advanced approach** contains a set of remote sensing options, which can be combined either in a direct or indirect assessment. More detailed and thus costly data is considered, such as LiDAR or RADAR data. Furthermore, advanced methods are suggested which can only be applied by remote sensing experts and might also need longer processing times, increasing 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 dependent on political decisions and may be placed 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, using more advanced tools helps to minimize the efforts for local experts and at the same time maintain the quality and (correct) heterogeneity of the output.
- **faster updates**: In the 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.

Deliverable 4.3 provides a comprehensive overview of data sources both existing and needed input data for biomass from forestry, agriculture and energy crops. This information is not included in the present document.

3.1 Basic approach

The basic approach is designed to satisfy the user requirements, primarily concerning costs and adaptability. 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 are. 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.

Deliverable 4.3 also provides detailed descriptions of work-flows for the basic approach. Below is an example of the “Basic approach” workflow for forestry.

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 here. This includes recovered wood (e.g. from demolished constructions, furniture etc. Below-ground biomass is also not considered. The reasons for this fact are threefold:

1) Harvesting of below-ground biomass is usually not a realistic option due to high harvesting efforts and costs: The stump removal costs are variable and depend on the 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.[13] 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 the 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. In contrast, the **advanced approach** 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 of biomass as national statistics.

The basic approach is shaped in order to make optimal use of existing data and products. The processing chain is sketched in 3 and described later on in this section.

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[13] For example: Forestry Encyclopedia (1953-1963). Forestry Encyclopedia, volume 1-3. Yugoslav Lexicographic Institute, Zagreb.

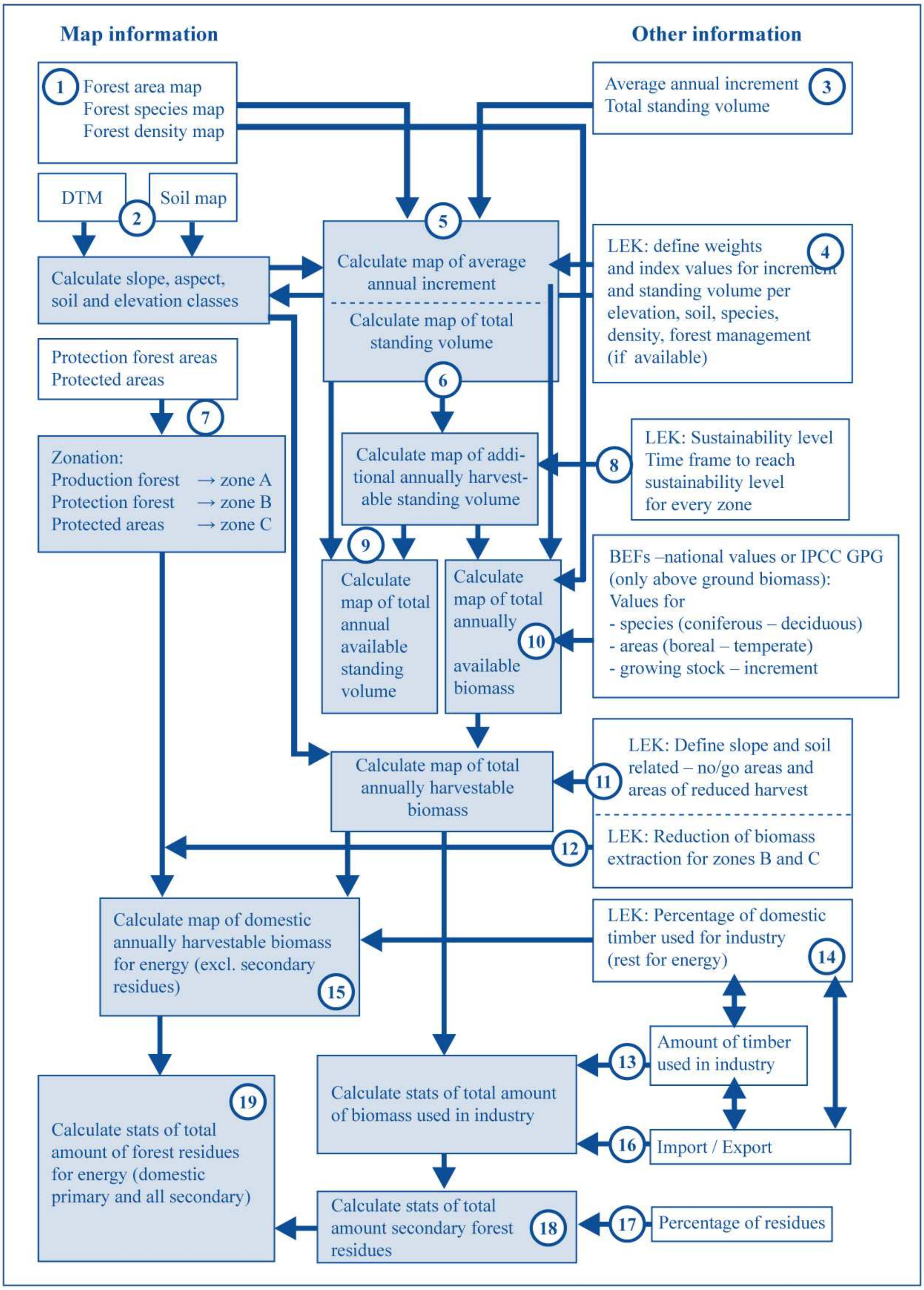

Figure 3: Processing chain for basic forest biomass for energy.

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 of the main document D4.3.

3) Use statistics about net **annual increment** (NAI) and **total standing volume** of forest biomass– basic figures from EUROSTAT and national NFI databases.

   NAI: m^3 over bark (total amount per country)

   Total standing volume: m^3 over bark (total amount per country)

4) Use **local expert knowledge (LEK)** 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 1 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 add up to 1.

Table 1: 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 2 for each parameter class ($Index_{classx}$: elevation class/ soil class/ species class/ density class/ forest management class)

   The values for each index should range between 0 and 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 2: 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 3 for NAI in relation to soil quality; yellow are the local expert inputs.

5) Calculate a **map of average annual increment** ($avNAI_{pix}$)
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 3 and Table 4.

Table 3: Calculation example 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	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	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	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	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} $= NAI - \sum(NAI_{WS}, NAI_{SS}, NAI_{ShS})$
Total	100 total forest area		45.5 Sum of pixels by index SPI $=\sum(PI_x)$	~ 21.9 Multiplication factor MF = NAI/SPI		1000 NAI (total NAI per country)

Table 4: Calculation example 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	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	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		68 Sum of	~ 14.7 Multiplica-		1000 NAI

	area		pixels by index SPI $=\sum(SPI_x)$	tion factor MF = NAI/SPI		(total NAI per country)

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

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 as:
$No_{inPar} = 2$ (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 above → result is a map with total growing stock per pixel ($avTGS_{pix}$). The calculation it basically done in the same way as for $avNAI_{pix.}$

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

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 **<u>protected areas map</u>** (Natura 2000 from EEA and national protected areas from national data sources) as well as with **<u>zones of protection forest</u>** (forest used as protection against avalanches etc., if existing) and divide the forest area into three zones:
   Zone A: ‘production forest area’
   Zone B: ‘protection forest area’ (if existing) and
   Zone C: ‘protected 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 m³ 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[14], 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.

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.

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

where

$\mathbf{TAAGS_{pix/zonex}}$ = **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 given in Deliverable D4.3. For the countries missing national information, the IPCC-GPG values[15] for the respective region (boreal or temperate) can be used. Since all countries considered in CEUBIOM are in 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. With this step, the total available above–ground biomass is 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**

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[14] MCPFE and FAO (2003). State of europe's forest 2003 - the mcpfe report on sustainable forest management in europe. online by Ministerial Conference on the Protection of Forests in Europe Liaison Unit Vienna, http://www.unece.org/timber/docs/sfm/europe-2003.pdf.

[15] IPCC (2006). Guidelines for National Greenhouse Gas Inventories, Volume 4: Agriculture, Forestry and Other Land Use. http://¬www.ipcc-nggip.iges.or.jp/¬public/¬2006gl/¬vol4.html. accessed 16 Feb 2009

13) Use **statistics** (EUROSTAT productions statistics, where existing, other countries can be filled up with national data, see data in D4.3) 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 a local expert knowledge for Austria is given in 4.

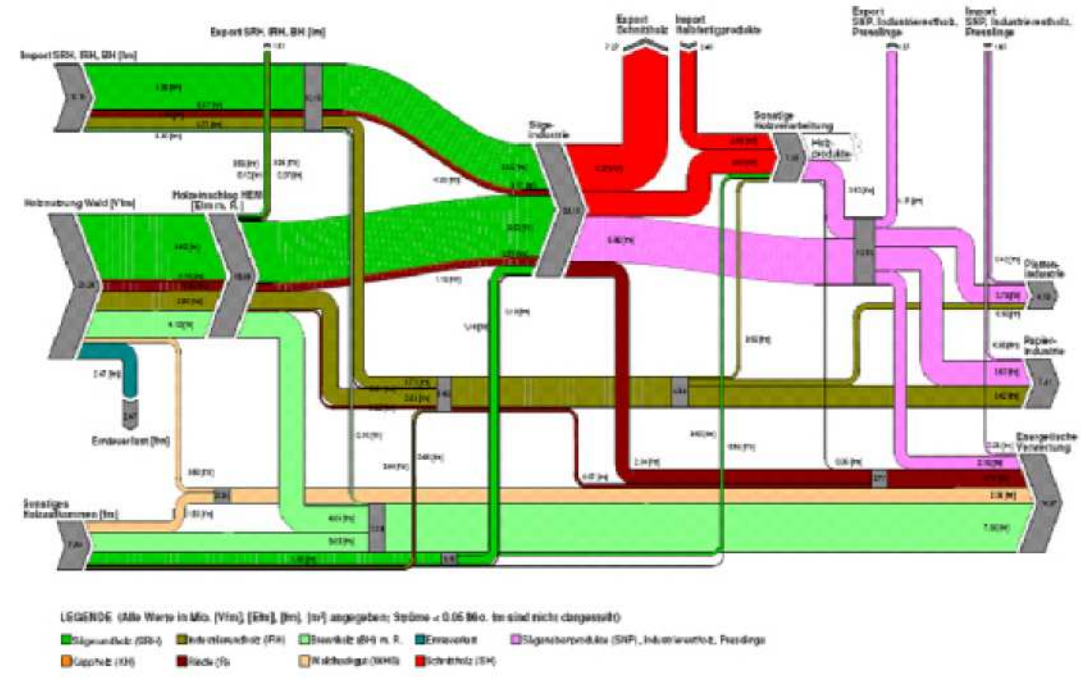

Figure 4: Timber/wood flow in Austria.[16]

15) Reduce the **amount of total domestic woody biomass** by the amount needed for industry and calculate a map of the 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.

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[16] Nemestothy, K. (2009). Energieholzmarkt in Österreich, volume 2/3/2009, chapter Holzbiomasse - Potenziale und Märkte, pages 26–34. Landwirtschaftskammer Österreich - Club Niederösterreich.

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 *the Annex 5 of the Deliverable D4.3*.

3.2 Advanced approach

Advanced approaches include utilizing more detailed data and more sophisticated methods from the remote sensing side than the basic approach. The input data for the advanced approaches for the different biomass types are much more heterogeneous than for the basic approach. These approaches allow for a more accurate theoretical potential to be developed if there are adequate financial resources available. However, the processing chain after the remote sensing component will be the same as described under the basic approach.

Below is an example of the "Advanced approach" workflow for forestry.

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.[17] 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 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.

LiDAR 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 5 with the inputs in light gray and the main processing steps in dark gray. The green 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. 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 is used, if available). 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.

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[17] Gallaun, H., Zanchi, G., Nabuurs, G.-J., Hengeveld, G., Schardt, M., and Verkerk, P. (2010). EU-wide maps of growing stock and above-ground biomass in forests based on remote sensing and field measurements. Forest Ecology and Management. in press, online available: doi:10.1016/j.foreco.2009.10.011.

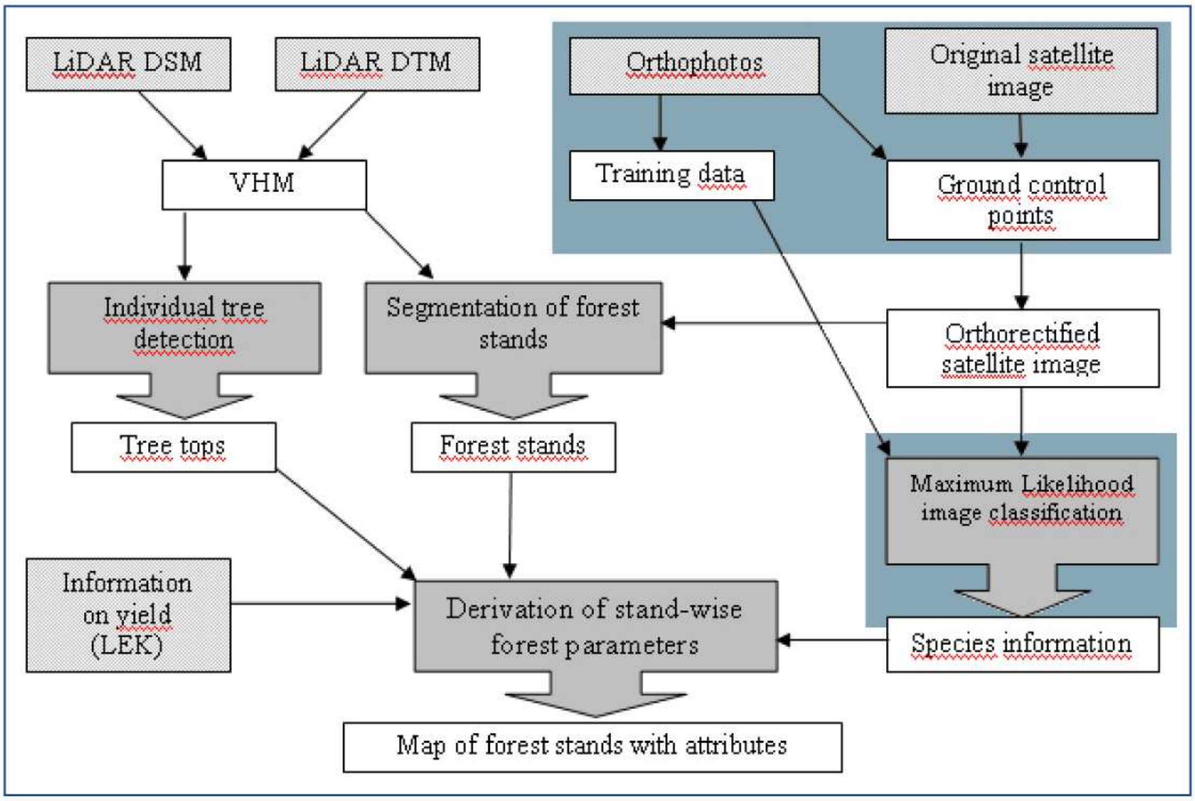

Figure 5: Overall process description

Individual tree detection

The method was developed at the Institute of Digital Image Processing, Joanneum Research[18] and is based on Laplacian-of-Gauss (LoG) filtering. For mathematical details on this filtering approach, see e. g. Gonzalez and Woods[19]. The procedure consists of the following steps; intermediate results are shown in Figure 6.

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 b, c and d. The dependence of the tree detection success from a single chosen sigma has been discussed by Chen et al[20].

2. A local maximum approach is performed on the original VHM, see Figure e.

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

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

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

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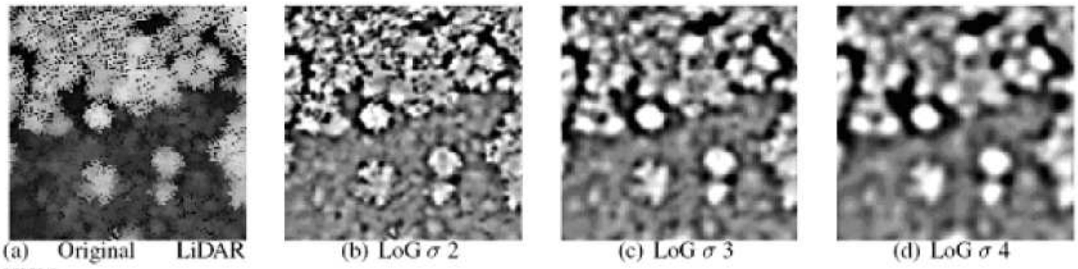
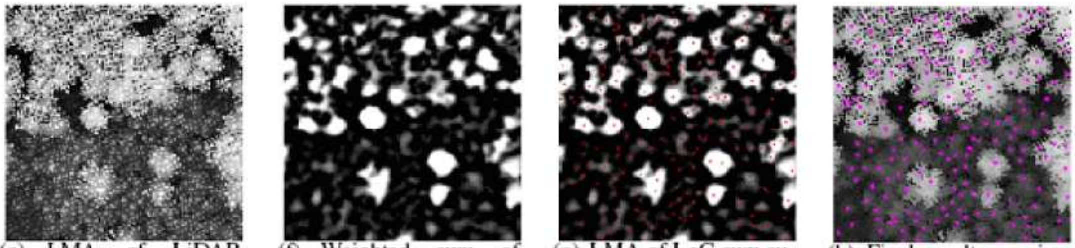
[18] Wack, R. and Stelzl, H. (2005). Assessment of forest stand parameters from laserscanner data in mixed forests. In Proceedings of ForestSat 2005, pages 56–60, Borås.

[19] Gonzalez, R. C. and Woods, R. E. (2002). Digital Image Processing. Prentice Hall, Inc., Upper Saddle River, New Jersey, second edition. 793 p

[20] Chen, Q., Baldocchi, D., Gong, P., and Kelly, M. (2006). Isolating Individual Trees in a Savanna Woodland Using Small Footprint Lidar Data. Photogrammetric Engineering & Remote Sensing, 72(8):923–932.



(a) Original LiDAR VHM (b) LoG σ 2 (c) LoG σ 3 (d) LoG σ 4



(e) LMA of LiDAR VHM (f) Weighted sum of LoGs (g) LMA of LoG sum superimposed on LoG sum (h) Final result superimposed on VHM

Figure 6: Processing steps and intermediate results for the LoG approach based on LiDAR data

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.

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 the 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.

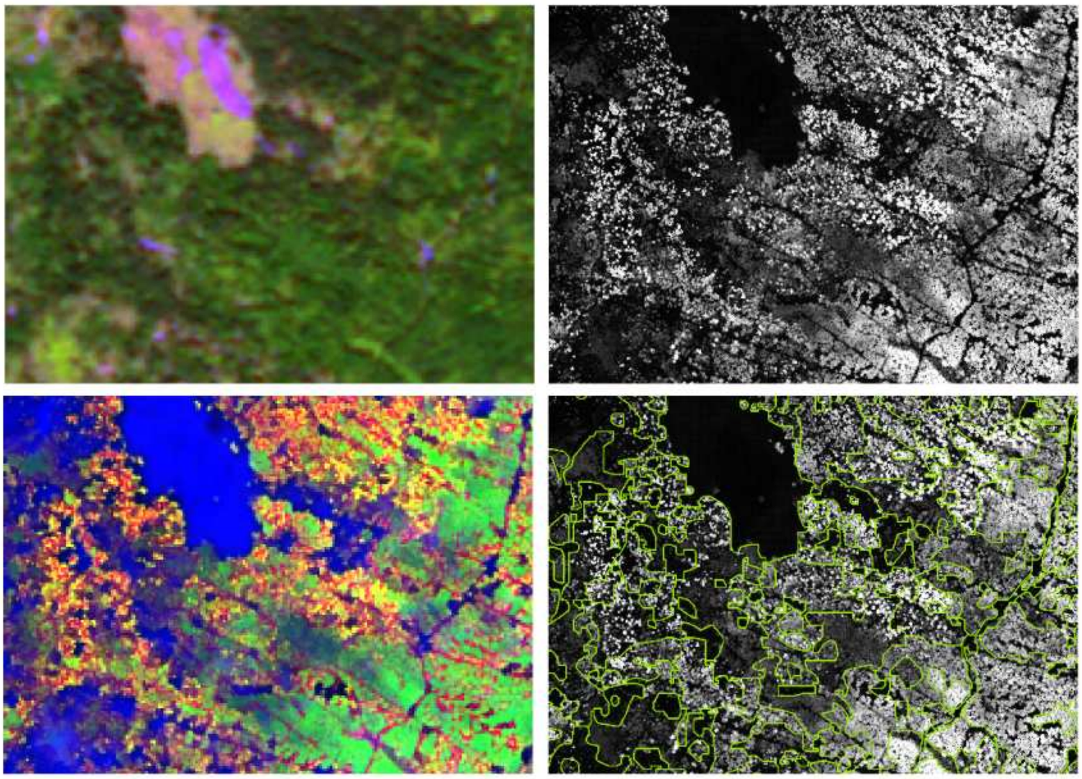


Figure 7: (a) SPOT image; (b) VHM; (c) artificial stack of properties; (d) VHM overlaid with segment borders

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 area above this threshold are considered as covered. By intersecting this information with the segments, the crown cover percentages can be calculated.

Stage of stand development:

There is a variety of definitions for different development stage, exemplarily, the one according to the yield tables from Badoux[21] are given in Table 6.

Table 6: 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:
As a first step for estimations, the total timber volume of the whole area is assessed statistically. This information is typically available through NFI. This amount is then distributed according to the waveform height distribution. To create a waveform like height distribution that shows the different stand characteristics, all laser points of a stand were accumulated according to their height above ground.

Detailed description of these parameters is available from literature[22]. 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[23] and for mixed forests in Austria with good results.

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

SAR 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 and trunk scattering. Le Toan et al presented models describing the relationship between forest biomass and SAR data[24].

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[21] Badoux, E. (1983). Ertragstafeln. Eidgenössische Anstalt für forstliches Versuchswesen. 3. Auflage

[22] Wack, R. (2006). Combined use of satellite imagery and laserscanner data for the assessment of forest stand parameters. In Proceedings of Workshop on 3D Remote Sensing in Forestry, Vienna.

[23] Wack, R., Schardt, M., Barrucho, L., Lohr, U., and Oliveira, T. (2003). Forest inventory for eucalyptus plantations based on airborne laserscanner data. In Proceedings of ISPRS Workshop on Laserscanning. available at: http://www.isprs.org/commission3/wg3/workshop_laserscanning/papers/Wack_ALSDD2003.pdf; accessed Jan. 2008.

[24] Le Toan T., A. Beaudoin, J. Riom and D. Guyon (1992). Relating forest biomass to SAR data in IEEE Trans. Geosci. Remote Sensing, 30, 403-411, 1992.

The model for obtaining Above Ground Biomass for forests and height of the trees is presented by Watanabe et al[25] . 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 that there is satellite data at L band available. 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[26] [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 point (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 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 entire processing chain is depicted in a simplified manner in Figure 8, for further details the reader is referred to CEUBIOM Deliverable D2.2.

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[25] Watanabe M.; M. Shimada; A. Rosenqvist, T. Tadono, M. Matsuoka; S.A. Romshoo, K. Ohta, R. Furuta, K. Nakamura, T. Moriyama, (2006). Forest structure dependency of the relation between L- band δ0 and biophysical parameters ; IEEE Transactions on Geoscience and Remote Sensing vol. 44 No 11

[26] Saatchi, S.S. Moghaddam, M. 2000 Estimation of crown and stem water content and biomass of boreal forest using polarimetric SAR imagery. IEEE Transactions on Geoscience and Remote Sensing Vol. 38, Issue 2, Part 1; pp 697-709

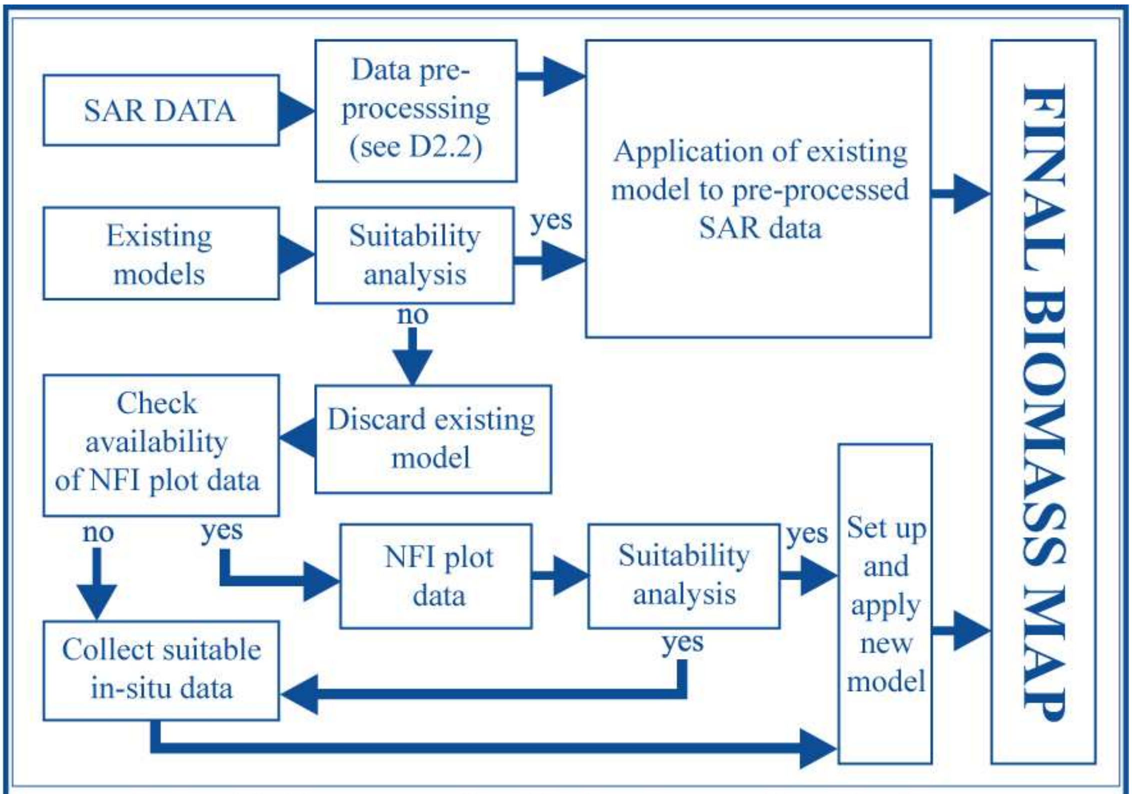

Figure 8: Simplified processing chain for forest biomass from SAR data

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.

4. Full Table of Contents of D4.3

As the purpose of this document is to obtain feedback from our end-users on the overall approach deployed in CEUBIOM it has been decided that only selected parts are included here and unnecessary levels of technical detail are avoided. In order to provide an overview of the structure of D4.3 the Table of Contents is presented here. The full version will be released after the integration of the comments and feedbacks.

- Annex 4: Stepwise guideline to generate basic remote sensing products for forestry (the Geoland 2 approach)
- Annex 5: Determination of the energy content of biomass
- Annex 6: Calculation of Slope and Aspect
- Annex 7: Source data
    - Annex 7.1: Forestry data available for each CEUBIOM partner country
    - Annex 7.2: Agricultural data available for each CEUBIOM partner country